U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A017 600

COMPARISON OF ECOLOGICAL IMPACTS OF POSTULATED OIL SPILLS AT SELECTED ALASKAN LOCATIONS

VOLUME I. INTRODUCTION, SUMMARY, METHODOLOGY, EVALUATION AND APPENDICES

MATHEMATICAL SCIENCES NORTHWEST, INCORPORATED

PREPARED FOR

COAST GUARD

JUNE 1975

KEEP UP TO DATE

Between the time you ordered this report—which is only one of the hundreds of thousands in the NTIS information collection available to you—and the time you are reading this message, several *new* reports relevant to your interests probably have entered the collection.

Subscribe to the **Weekly Government Abstracts** series that will bring you summaries of new reports *as soon as they are received by NTIS* from the originators of the research. The WGA's are an NTIS weekly newsletter service covering the most recent research findings in 25 areas of industrial, technological, and sociological interest—invaluable information for executives and professionals who must keep up to date.

The executive and professional information service provided by NTIS in the **Weekly Government Abstracts** newsletters will give you thorough and comprehensive coverage of government-conducted or sponsored research activities. And you'll get this important information within two weeks of the time it's released by originating agencies.

WGA newsletters are computer produced and electronically photocomposed to slash the time gap between the release of a report and its availability. You can learn about technical innovations immediately—and use them in the most meaningful and productive ways possible for your organization. Please request NTIS-PR-205/PCW for more information.

The weekly newsletter series will keep you current. But *learn what you have missed in the past* by ordering a computer **NTISearch** of all the research reports in your area of interest, dating as far back as 1964, if you wish. Please request NTIS-PR-186/PCN for more information.

WRITE: Managing Editor
5285 Port Royal Road
Springfield, VA 22161

Keep Up To Date With SRIM

SRIM (Selected Research in Microfiche) provides you with regular, automatic distribution of the complete texts of NTIS research reports *only* in the subject areas you select. SRIM covers almost all Government research reports by subject area and/or the originating Federal or local government agency. You may subscribe by any category or subcategory of our WGA **(Weekly Government Abstracts)** or **Government Reports Announcements and Index** categories, or to the reports issued by a particular agency such as the Department of Defense, Federal Energy Administration, or Environmental Protection Agency. Other options that will give you greater selectivity are available on request.

The cost of SRIM service is only 45¢ domestic (60¢ foreign) for each complete microfiched report. Your SRIM service begins as soon as your order is received and processed and you will receive biweekly shipments thereafter. If you wish, your service will be backdated to furnish you microfiche of reports issued earlier.

Because of contractual arrangements with several Special Technology Groups, not all NTIS reports are distributed in the SRIM program. You will receive a notice in your microfiche shipments identifying the exceptionally priced reports not available through SRIM.

A deposit account with NTIS is required before this service can be initiated. If you have specific questions concerning this service, please call (703) 451-1558, or write NTIS, attention SRIM Product Manager.

This information product distributed by

NTIS U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

332057

Report No. CG-D-155-75
Task No. 4108.2.9

June 1975

ADA017600

COMPARISON OF ECOLOGICAL IMPACTS OF POSTULATED OIL SPILLS AT SELECTED ALASKAN LOCATIONS

Introduction, Summary, Methodology, Evaluation and Appendices

J. S. ISAKSON
J. M. STORIE
J. VAGNERS
G. A. ERICKSON
J. F. KRUGER
R. F. CORLETT

JUNE 1975

FINAL REPORT

VOLUME I

Document is available to the the public through the
National Technical Information Service,
Springfield, Virginia 22151

PRICES SUBJECT TO CHANGE

Prepared for

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington, D. C. 20590

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its content or use thereof.

The contents of this report do not necessarily reflect the official view or policy of the Coast Guard, and they do not constitute a standard, specification or regulation.

This report, or portions thereof, may not be used for advertising publication, or promotional purposes. Citation of trade names and manufacturers does not constitute endorsements or approval of such products.

W. L. KING
Captain, U. S. Coast Guard
Chief, Environmental and
Transportation Technology Division
Office of Research and Development
U. S. Coast Guard Headquarters
Washington, D. C. 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-155-75		

4. Title and Subtitle	5. Report Date
COMPARISON OF ECOLOGICAL IMPACTS OF POSTULATED OIL SPILLS AT SELECTED ALASKAN LOCATIONS Vol. I: Introduction, Summary, Methodology, Evaluation and Appendices	June 1975 6. Performing Organization Code
7. Author(s) MATHEMATICAL SCIENCES NORTHWEST, INC.	8. Performing Organization Report No.
9. Performing Organization Name and Address Mathematical Sciences Northwest, Inc. 2755 Northup Way P. O. Box 1887 Bellevue, Washington 98004	10. Work Unit No. 4108.2.9 11. Contract or Grant No. DOT-CG-42913-A 13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Department of Transportation United States Coast Guard Office of Research and Development Washington, D.C. 20590	Final Report 14. Sponsoring Agency Code U. S. Coast Guard

15. Supplementary Notes

This report consists of two volumes. Volume I contains the introduction, summary, methodology, evaluation, and appendices. Detailed results for each of the study locations are contained in Volume II.

16. Abstract

A ranking of potential environmental impact for spills of crude oil, diesel-2, bunker C, and gasoline in amounts ranging from 100 to 50,000 barrels was made for specific sites at Yakutat Bay, Valdez Harbor, Valdez Narrows, Drift River Channel, Port Graham, Kamishak Bay, Unimak Pass, Port Moller, Kvichak Bay, St. Matthew Island, Offshore Prudhoe, Onshore Prudhoe, Nome, Cape Blossom Channel, Colville River, Yukon River, and Denali Fault. Spills were assumed to disperse from inertial, viscous, surface tension, wind and current forces. Most probable wind and current conditions were utilized. Sites were characterized in terms of eight species habitats. Most probable cases were evaluated.

A rating system was devised to characterize the impact based upon estimated species abundance, importance of species, and the impact of oil on such species over the short and long term. Impacts were estimated with the use of three-dimensional matrices. The highest impact ratings were obtained for spills at Port Graham, Valdez Narrows, Unimak Pass, and the Yukon River Crossing, assuming no spill cleanup.

The same five locations dominated the impact ratings where containment/cleanup were assumed to take place.

Data gaps were noted and future studies are recommended.

17. Key Words	18. Distribution Statement
Oil Spill Environmental Impact Alaska Computer Modelling Matrix Evaluation	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages
Unclassified	Unclassified	633

Form DOT F 1700.7 (8-69)

FINAL REPORT

VOLUME I

COMPARISON OF ECOLOGICAL IMPACTS OF POSTULATED OIL SPILLS AT SELECTED ALASKAN LOCATIONS

Introduction, Summary, Methodology, Evaluation and Appendices

Prepared For

United States Coast Guard
Washington, D.C. 20590

Contract DOT-CG-42913-A

June 1975

By

J.S. Isakson
J.M. Storie
J. Vagners
G.A. Erickson
J.F. Kruger
R.F. Corlett

MATHEMATICAL SCIENCES NORTHWEST, INC. (MSNW)
2755 Northup Way
Bellevue, Washington 98004

TABLE OF CONTENTS -- VOLUME I

TABLE OF CONTENTS -- VOLUME I (CONT'D)

TABLE OF CONTENTS -- VOLUME I (CONT'D)

TABLE OF CONTENTS -- VOLUME I (CONT'D)

TABLE OF CONTENTS -- VOLUME I (CONT'D)

TABLE OF CONTENTS -- VOLUME I (CONT'D)

APPENDICES

LIST OF TABLES--VOLUME I

LIST OF TABLES--VOLUME 1 (CONT'D.)

LIST OF FIGURES--VOLUME I

LIST OF FIGURES--VOLUME I (CONT'D)

SECTION 1. INTRODUCTION

Under authority of the Water Pollution Control Act, the United States Coast Guard has been assigned the responsibility of promulgating and enforcing regulations concerning oil pollution in United States waters. The Coast Guard may also be called upon to assist with inland oil pollution incidents by virtue of its presence and operational capability.

This responsibility has caused the Coast Guard to undertake planning programs to expand its capabilities to respond to pollution incidents. Previous efforts in this regard have included studies concerning the location of potential oil spills, the behavior of spilled oil, and the logistical considerations associated with response to oil spill incidents. Land and water areas in Alaska are of special significance to the Coast Guard because of the concentration of oil exploration, production, and associated transportation activities within the State and its adjacent waters. Previous studies led to the identification of 17 Alaskan locations where the potential for oil spills was believed to be greatest.

On June 28, 1974, the Coast Guard contracted with the research and consulting firm Mathematical Sciences Northwest, Inc. (MSNW), Bellevue, Washington, to perform a detailed examination of these locations and to identify the environmental damage to be expected from local oil spills. At the 17 locations, different spill amounts, volumes, modes, seasons, and oil types were analyzed in the work. The damage caused by oil spills that were allowed to dissipate naturally and the damage that might result from actions to clean up a spill were both examined.

This report presents the findings of the study. It is presented in two volumes. Volume I includes the Introduction (Section I), Summary (Section 3), general discussions of the environmental effects of oil spills (Section 4), how oil disperses when spilled (Section 5), and spill cleanup methods (Section 6). The first volume also includes specific information as to the methods used for evaluating spill impacts in this study (Section 7), a description of the particular cases considered (Section 8), the cataloging procedure to obtain data for the 17 spill locations (Section 9), and a discussion of future studies needed to more accurately evaluate the effect of spills (Section 10), and Appendices A-E. Volume II includes the Results (Section 2).

The matrix evaluation system for environmental impact analysis was developed jointly by Messrs. James F. Kruger, Planner; Gerald A. Erickson, Engineering Scientist; John S. Isakson, Marine Biologist, and J. Michael Storie, Systems Analyst. The matrix system was automated by Mr. Robert H. Klug, Programmer/Analyst.

The oil spill simulation model was developed by Mr. Storie, assisted by Ms. Marianne M. Montgomery, Associate Analyst, and Ms. Lois I. Storie, Data Preparation.

In addition, Mr. Isakson was the Principal Investigator for the definition of biological resourses; Dr. Erickson and Mr. Kruger for the analysis of wind and current data, and Mr. Kruger for initial matrix scoring followed by interactive evaluations by the study team.

Ms. Cheryl L. Oprea, Administrative Secretary, coordinated report preparation. Mr. Richard F. Corlett, Vice President, Engineering, was the Project Director.

Dr. Juris Vagners, Associate Professor, University of Washington, was the Principal Investigator for characterization of oil spreading dynamics and spill cleanup methods. He drew upon the advice of Dr. David P. Hoult, managing partner of Hoult and Co.; Dr. Charles Sleicher, Professor, University of Washington, and Dr. Seeyle Martin, Associate Professor, University of Washington, in regard to matters of oil spread dynamics, dispersion in water columns,and weathering. Dr. Albert W. Erickson, Professor, University of Washington, provided program input related to wildlife biology. Dr. Phillip A. Lebednik, University of British Columbia, provided program input related to marine flora and oil impacts on these plants. Mr. Edgar A. Best, International Pacific Halibut Commission, provided information concerning marine fisheries. Mr. Larry G. Gilbertson, University of Washington, assisted the study team with respect to salmon fisheries. Mr. Charles A. Simenstad, University of Washington, provided information on marine invertebrates and investigated the effects of oil on fauna for the study. Dr. Rita A. Horner, formerly with the University of Alaska, Institute of Marine Science, provided program information related to Arctic Coast biology.

The project team is especially appreciative of the advice and information provided by Mr. Theodore R. Merrell, National Marine Fisheries Service--Auke Bay, and Mr. Robert C. Clark, National Marine Fisheries Service, Seattle. Other sources consulted for information are described in Section 9.

SECTION 2. RESULTS OF THE ESTIMATED IMPACT OF OIL SPILLS IN THE ALASKAN ENVIRONMENT

This section presents the analysis of the estimated environmental impact of oil spills at 17 locations in Alaska. Thirteen of the locations are along the coast and four are inland near the Colville and Sagavanirktok rivers on the North Slope and the Yukon and Denali Fault Trans-Alaska Pipeline crossings.

Hypothetical oil spills at the locations are initially discussed under the assumption that no spill cleanup countermeasures are employed. The analysis addresses the impacts of four oil types--crude, bunker C, diesel-2, and gasoline; seasons of importance or ice and no-ice; spill size--100 to 50,000 barrels, and spill mode--tanker, barge, drilling rig, pipeline, transfer, ballast, and miscellaneous. Each spill was treated as an "instantaneous" discharge, i.e., all the oil was released in a short time rather than leaking out over a period of hours or days. Subsection B treats impact with the associated changes due to applicable cleanup strategies. Numerical scores are tabulated through an impact matrix, and the sites and spill scenarios are ranked in order from highest impact to least impact. Subsection C ranks the various spill cases in estimated order of impact severity.

Each site is described in regard to its location and its physical and biological characteristics. At each site, the spill cases are discussed and compared without cleanup, and a separate section of cleanup cases at each site describes the changes in ecological impact due to cleanup activities. This section contains the results for almost 500 spill cases and its necessary length requires that it be placed in a separate volume. Therefore, the complete analysis of the results is presented in <u>Volume II</u>.

SECTION 3. SUMMARY

A. PURPOSE

The purpose of the study was to perform an intensive six-month study of the environmental impact resulting from potential oil spills at 17 locations in Alaska in order to rank the various types and locations of oil spills according to impact severity. In addition, a similar ranking of severity was prepared assuming that practical means to clean up spills were employed. It was recognized by the Coast Guard and MSNW that this first study of an extremely complex subject would be pioneering in nature. As such, it was expected that the study would develop a methodology for studies of this nature, apply the methodology to produce an initial analysis of environmental impacts, and identify further research needs.

B. SCOPE

Five key factors define the scope of the study. They are spill location, spill mode, spill volume, spill type, and seasonal considerations.

The locations selected for analysis were:

- Offshore Yakutat
- Valdez Harbor
- Valdez Narrows
- Drift River
- Offshore Port Graham
- Kamishak Bay
- Unimak Pass
- Port Moller

- Kvichak Bay
- St. Matthew Island
- Nome
- Cape Blossom
- Offshore Prudhoe
- Onshore Prudhoe
- Umiat
- Yukon River Crossing
- Denali Fault Crossing

The spill modes considered were:

- Tanker Casualty
- Drilling Rig Discharge
- Tanker Transfer Operation
- Tanker Ballast Discharge (uncontrolled)
- Miscellaneous Spills
- Pipeline Failure
- Barge Casualty (refined products only)

Spill volumes ranged from 100 to 50,000 barrels. Oil types selected for study were crude oil, diesel-2, bunker C, and gasoline. Seasonal considerations included the presence or lack of sea (or river) ice, species abundance, and meteorological factors. Biological impact was estimated exclusively; the direct impact of oil spills on man and man-made structures was not considered. No other existing pollutants, nor chronic oil pollution, were considered. Impacts evaluated were for "once-only" events.

Three hundred seventy-two individual cases were eventually examined where oil dispersion was assumed to proceed by natural processes. Twenty-two additional cases were analyzed wherein oil spill cleanup was assumed to take place. Non-cleanup cases were modelled for 72 hours of oil dispersion as a a basis for these analyses.

C. METHODOLOGY

This study was based on existing data; no field work was performed. Spills were assumed to occur instantaneously in all cases under consideration, with instantaneous spills defined as release of the total volume of oil within the first hour of the scenario.

The model MSNW developed for simulating oil spill dispersion was based on calm sea spreading theory and empirically derived dispersion formulae accounting for wind and current effects. As requested by the USCG, "most probable" conditions and resultant spills were evaluated. The search for "worst possible" scenarios was beyond the scope of this study. A time history of oil slick boundary points, subject to spreading and dispersion effects, was calculated. In this fashion, the overall trajectory of the slick centroid, as well as the areal extent of the slick, is simulated. The slick shape may become distorted as a result of current, wind, and spreading vector interactions. The model assumes that spread is governed by inertial, viscous, and surface tension forces as a function of time in addition to current and wind effects.

Most probable wind conditions were developed for each spill scenario based upon an interpretation of shore-based station data. Winds were assumed constant over the 72-hour duration of each simulation. Currents were obtained from existing tidal current tables, the *COAST PILOT*, or interpreted from these and other sources. The simplifying assumption was made that the tidal cycle could be approximated by a sine wave having a 12-hour period.

In enclosed waters, tidal current magnitudes and directions were defined as functions of physiography and then superimposed on the sine wave as functions of time. For open-sea conditions where no discernible ebb and flood exists, the model treats currents as a function of wind direction, taking account of the coriolis effect.

Winds rarely remain steady in terms of either speed or azimuth. Moreover, available current data were sparse and not descriptive of the subtleties of backeddies and tide rips. In order to take into account uncertainties due to these factors, as well as variability of physical/chemical properties with environmental parameters (temperature, wind, etc.), MSNW "enveloped" the spill areas calculated from the computer model. It must be emphasized that the areal extent of an envelope does not represent an area covered by a specific spill, but rather that the spill, as calculated by the model, is equally likely to have passed over any region included in the envelope.

Spills under ice were conservatively assumed to spread unimpeded to the maximum area as estimated by previous investigators. Spills on ice surfaces were assumed to spread to a minimum thickness of 1 cm.

Specific spill sites were selected by MSNW and approved by the U.S. Coast Guard, taking account of such factors as navigation routes, critical turn radii of vessels, depth of water, natural hazards, location of terminals, projected drilling sites, etc.

For purposes of biological impact evaluation, the spilled material was assumed to be present to a depth of 10 fathoms. Gasoline was assumed to evaporate rapidly with time, and a maximum simulation time of 24 hours was defined. Any oil reaching a beach was assumed to remain on the beach.

The characterization of biotic communities at the different locations and in all of its variations would, of course, require an immense effort. Not surprisingly, the data that are available at this time are limited in both depth and extent. MSNW elected to characterize the sites in terms of habitats. The eight selected habitats were: pelagic, subtidal sand/mud, subtidal rock/cobble/gravel, intertidal sand/mud, intertidal rocky, intertidal cobble/gravel, freshwater river, and terrestrial. Floral and faunal types present in each type of habitat were deduced from research reports of record or the judgment of study team members who have visited the different locations. Alyeska reports provided some summary information for land sites. Other reports by federal and state agencies provided information that was used as a basis for extrapolating types and abundance of biological species at locations where no such information was available.

A rating system was devised by MSNW to characterize the impact of an oil spill. The system may be characterized as three-dimensional in nature; the dimensions being:

- Abundance of floral and faunal species
- Importance of species to man and the location's ecology.
- The impact of oil or its derivatives on species, short and long-term.

Commercial, recreational, and subsistence factors were used to define the importance to man. With respect to ecological importance, value in food chains and status with respect to endangered and protected species was considered.

It was necessary to assign numerical values to each axis in every case examined (numbering in the hundreds). A multiplicative procedure was followed in order to obtain an overall impact score for each case, i.e., the abundance rating was multiplied by the summed importance ratings and the result by both short and long-term impact ratings. The final impact score for a particular spill case was derived from the short and long-term impact ratings for each species. The critical problem of assigning weighting values was accomplished by means of a reiterative, subjective, team evaluation process. Each site was cross-correlated with others with respect to species abundance and importance before total impact scores were calculated. Needless to say, the resulting three-dimensional matrix was computerized for ease of manipulation.

D. STUDY LIMITATIONS

The point was made in the previous subsection that wind and current data for the various spill cases were sparse and may not be representative of actual spill situations that can occur. The use of an enveloping procedure in an attempt to conservatively offset these uncertainties in defining oil spreading trajectories was also discussed. Finally, the use of conservative assumptions with respect to the effect of ice presence on spreading dynamics was noted.

It should be recognized that spills can occur at specific sites different from those assumed for this study. If so, the degree of impact could be substantially greater or less than that estimated herein. Spills also might occur over an extended area instead of at a precise location as, for example, occurred with the Drift River spill in December of 1967. In that instance, the damaged tanker was towed to Nikiski and oil leaked into Cook Inlet along a path of many miles, thus contributing to its subsequent spread over a large area.

Other factors contribute to the need to exercise caution in applying the results of this study. One is the fact that the amount of oil spilled could be greater or less than that assumed at the locations surveyed. The VLCC Metula spilled an estimated 400,000 bbls of crude oil in the Straits of Magellan on August 9, 1974. This is 8 times the maximum spill assumed in this study. Another is the fact that wind and current speeds and direction could differ in magnitude and direction from those used in the study. Still another is the fact that chronic oil presence, or the presence of other types of pollutants at the time a new spill occurred, could influence the severity of spill impacts. It should be recognized that the limitations of the study were partially dictated by the purpose--a relative ranking of likely impact. Most likely spill sizes, locations, and climatic conditions were used as a more equitable basis for relative ranking of the sites. The scope did not call for worst scenarios imaginable.

Finally, readers should bear in mind that MSNW followed a traditional approach in estimating the biological severity of spills. That is, sites having the greater diversity of animal and plant life received the highest impact rating; sites having a lower estimated diversity of flora and fauna scored lower for a given spill type and amount. Other researchers would argue that locations with low diversity are more fragile--and the consequences of oil spills are thereby greater. This point was partially addressed by the long-term impact effect used in the matrix evaluations.

In summary, the study results should be treated as a "first-cut" and best estimate of extremely complex situations based upon limited data. The numerical scores should be treated simply as tools used by the investigators in assessing the relative impact of spills at different locations. The numerical scores have no absolute meaning in themselves.

E. RESULTS

The U.S. Coast Guard's primary objective in scheduling this study was to obtain a ranking of the relative environmental impact of oil spills at different locations. Section 2 presents such a ranking for 372 spill scenarios analyzed by the study team. In addition to these scenarios, for which natural dissipative forces were assumed to control the spread of oil, the study team also analyzed 22 scenarios in which spill cleanup measures were assumed to be used.

The 20 non-cleanup cases for which the greatest environmental impact was estimated occurred in South Central Alaska, with the exception of one case involving a large simulated spill at the Yukon River Pipeline Crossing. In addition to the Yukon River Crossing, the cases found to have the greatest impact involved Port Graham, Valdez Narrows, Drift River, and Unimak Pass. The highest impact score that was obtained involved a spill of 50,000 barrels of diesel-2 at Port Graham in the Summer. The second highest score involved a 10,000-bbl spill of diesel-2--also at Port Graham. Cases involving Valdez Narrows and Port Graham dominated the 20 cases of highest impact. One-half of this group involved diesel-2 fuel oil. Seventeen of the 20 highest score cases took place in the Summer, and 13 of the 20 cases involved the maximum spill size encompassed by the study--50,000 barrels (the remaining 7 were 10,000-bbl spills). The results reflect the higher species abundance and diversity at these sites. The high abundance approach is controversial as noted in Subsection D - Study Limitations.

The same five locations, Valdez Narrows, Port Graham, Unimak Pass, Yukon River Crossing, and Drift River dominated the list of high impact scores in those cases where containment and cleanup of spilled oil was assumed to take place.

At Valdez Narrows, barriers, skimming devices, and sorbents were assumed to be used effectively in the water while mechanical/manual removal and on-site sand cleaning were assumed to be effective for oil removal on the beaches. The same mix of containment and cleanup techniques was assumed to be effective at Port Graham and Drift River. Unimak Pass proved to be a special situation where none of the water containment or cleanup techniques appeared to be particularly useful. Mechanical/manual removal, burning and natural dispersion were assumed to be reasonably effective for beach/land cleanup. Sorbents and manual removal were assumed to be effective for Yukon River Crossing spills in Summer and were judged useful in the Winter if the oil remains on the ice surface. Burning and mechanical/manual removal were assumed to be effective for oil removal on Yukon River banks.

The highest impact score for cleanup scenarios was obtained for a 50,000-bbl spill of diesel-2 at Port Graham during the Summer. The second highest score obtained was for a similar spill at Valdez Narrows.

MSNW was instructed to avoid direct comparison of cleanup and non-cleanup cases for specific events and locations. Some general conclusions can be drawn, however.

In enclosed waters where tidal currents are significant and fetches are short, beach habitats can be rapidly impacted (in some cases within one hour after the spill occurs) unless containment equipment is deployed in near-instantaneous fashion. In other cases that were analyzed, longer times, on the order of 3 to 4 hours or more, elapsed before oil reached the nearshore habitats. This latter type of situation permits more time for deployment of containment equipment, and such deployment may yield positive results. Ice, when present, was assumed to preclude use of containment equipment and oil was presumed to disperse under, on, or with the ice.

The effectiveness of cleanup must be decided on a case-by-case basis. While cleanup techniques can be used to eliminate oil dispersed on beaches, it is not known what the overall effect will be. MSNW assumed for purposes of the study that the short-term effect of such efforts would be detrimental in intertidal areas, but that the long-term effect in such areas would be positive. This was an assumption that is not currently subject to verification. Notably lacking from the current state-of-the-art is knowledge of the repopulation dynamics of beaches that have been effectively sterilized by the use of some beach cleanup techniques. It is not known whether the overall benefit of using such techniques is positive or negative at all Alaska locations of interest.

Consistent with the pioneering nature of this study, the U.S. Coast Guard also requested that MSNW identify data gaps and recommend future studies to fill such gaps and improve the methodology of spill impact analysis and avoidance planning.

Important data gaps exist with respect to the following:

- Descriptions of local biological species and abundance
- Species relationships within food webs
- Species population and repopulation dynamics
- Short and long-term effects of oil on species
- The economic value of various species
- Local tidal current information
- Characteristics of rivers downstream of TAPS crossings
- Nearshore ice dynamics
- Oil dispersion under ice
- Oil degradation characteristics under Arctic conditions
- Spill history data with which to "ground truth" oil spread prediction models
- The effects of combusting recovered oil on the ecology and albedo over Arctic ice
- The performance of oil containment and pickup equipment in the presence of sea ice

Recommendations for studies needed to help fill these data gaps are made in Section 10. In addition, studies are recommended concerning network monitoring of wind speed and direction, pre-selection of spill response staging areas, the impact of fertilization on oil degradation, the analysis of preferred tanker routes and control systems, and the design and location of shoreside transfer and storage facilities to minimize potential spill impact.

An overriding judgment gained from this study is that Alaska is a large and often hostile environment in which oil spills will probably occur.

With the problems of logistics, adequate cleanup methods, environmental impact, and other cleanup problems including high costs, efforts must be directed to the prevention of oil spills in Alaska.

SECTION 4. EFFECTS OF OIL ON THE ENVIRONMENT

This section addresses the effects of crude oil and refined products on the biological and physical environment. Key assumptions made by MSNW for purposes of this study are also noted. With respect to the study, primary dependence was placed upon References 1-7, which summarize state-of-the-knowledge of oil effects on the environment. Subsections A through D which follow discuss effects of petroleum and its products on the biological environment. Subsection E addresses effects on the physical environment.

A. GENERAL

The complexity of interpreting the effects of oil on the biological environment is illustrated by the numerous factors that influence the damage caused by a spill. Factors identified by Straughan[8] and by Brooks, et al.,[9] are:

1. Type of oil spilled
2. Amount of oil spilled
3. Location of spill
4. Time of year
5. Distribution of ice
6. Direction and velocity of currents and winds
7. Silt burden or turbidity of the water
8. Abundance and distribution of organisms
9. Previous exposure of the area to oil
10. Presence of other pollutants
11. Method of spill control

Information sufficient to define the first three factors was stipulated by the USCG. MSNW assembled the basic data or formed assumptions needed to define factors 4 through 8 and 11. No attempt was made to address chronic oil spill problems or the presence of other pollutants (factors 9 and 10, respectively) in this study.

The impact of petroleum and refined products on biological species has been classified by the Council of Environmental Quality[7] as follows:

1. Lethal toxicity
2. Sub-lethal disruption of physiological or behavioral activities
3. Effect of direct coating by oil
4. Incorporation of hydrocarbons in organisms which cause tainting or accumulation of hydrocarbons in food chains.
5. Changes in biological habitats

Unfortunately, the state-of-the art is such that practically no information exists with respect to factor numbers 2, 4, and 5 in terms of Alaskan species. As a result, impact evaluations performed in this study were based primarily on lethal toxicity (factor number 1) and the effect of direct coating by oil (factor number 3). Published information with respect to even these two factors is limited in extent for Alaskan species.

Another categorization of oil spill effects that combines these five types of impacts is what can be called "chemical" and "physical" impacts. The "chemical" impacts would be those resulting from the chemical properties of the oil (i.e., such as the toxicity of soluble aromatics on some aquatic organisms). Normally, the exposure of different species to chemical impacts following an oil spill would be of short duration because of the volatility of some of the materials involved. Blumer and Sass[10] and others have shown, however, that the chemical impact of diesel-2 may be of long duration in confined locations such as salt marshes.

"Physical" impacts are those resulting from the physical properties of oil (i.e., smothering of intertidal organisms or coating of bird feathers). These impacts are usually more noticeable some time after a spill, although a marine spill nearshore or a land spill can create a physical impact immediately after a spill has occurred. Physical impacts are generally of longer duration.

As developed in Section 5 of this report (Dispersion and Fate of Oil in the Environment), the lighter fractions of spilled oil will tend to evaporate and disperse such that their capacity to cause biological impact will be greatly diminished after a few hours. MSNW concluded that the impact would be significantly reduced after about 12 hours in most situations. There will obviously be exceptions to this generalization; exceptions include situations where emulsification, vigorous vertical dispersion of the oil, and early capture of the oil by shoreside sediments occur. In general, however, it is concluded that the chemical impact of a spill will manifest itself most strongly in the first 12 hours. The capacity of a spill to cause physical impact will be operative over much longer periods. MSNW adopted a 72-hour period for purposes of spill impact evaluation and assumed that physical impact capacity remained undiminished over this period.

Still another generalization can be made that major impacts of lighter refined oils (diesel-2, gasoline) are chemical, while major impacts of crude oils and residual oils (bunker-C) are the physical type. Figure 4-1 illustrates some minimum persistence of weathered oil by marine habitat type (not the same habitats that MSNW used in the evaluation matrices).[6]

This pattern of chemical and physical impacts was utilized to form two generalized envelopes of spill impact areas after cases were modelled (a 12-hour and 72-hour envelope). The envelopes and the physical shoreline makeup (i.e., sand, mud, rock, etc.) were used in judging and scoring short-term and long-term impacts of a specific spill in the evaluation matrix for that case.

Another point to be made is the general lack of information about the impact of oil on biological organisms in general and the lack of information of impacts on Alaskan organisms. The terrestrial impacts of oil development and oil spills in the Arctic have been under investigation for some time and a data base is developing. Work on Alaskan aquatic organisms is in its infancy with work just beginning at the University of Alaska and National Marine Fisheries Service at Auke Bay (Juneau), Alaska.

A problem with some of the referenced experimental studies on aquatic organisms is that many researchers have confused the "dose" of oil used (i.e., the amount of the oil product added) to the true "concentration" of oil (i.e., the amount and types of oil products in the water column below the oil added to the surface) that actually killed or injured the organism(s). This important aspect of some of the existing data base on oil effects on organisms is discussed in detail by Legore.[11] He goes on to illustrate one case in which a stated "concentration" (really a dose) that was a 96-hour median tolerance limit (TLM) for a fish species was over twice the solubility

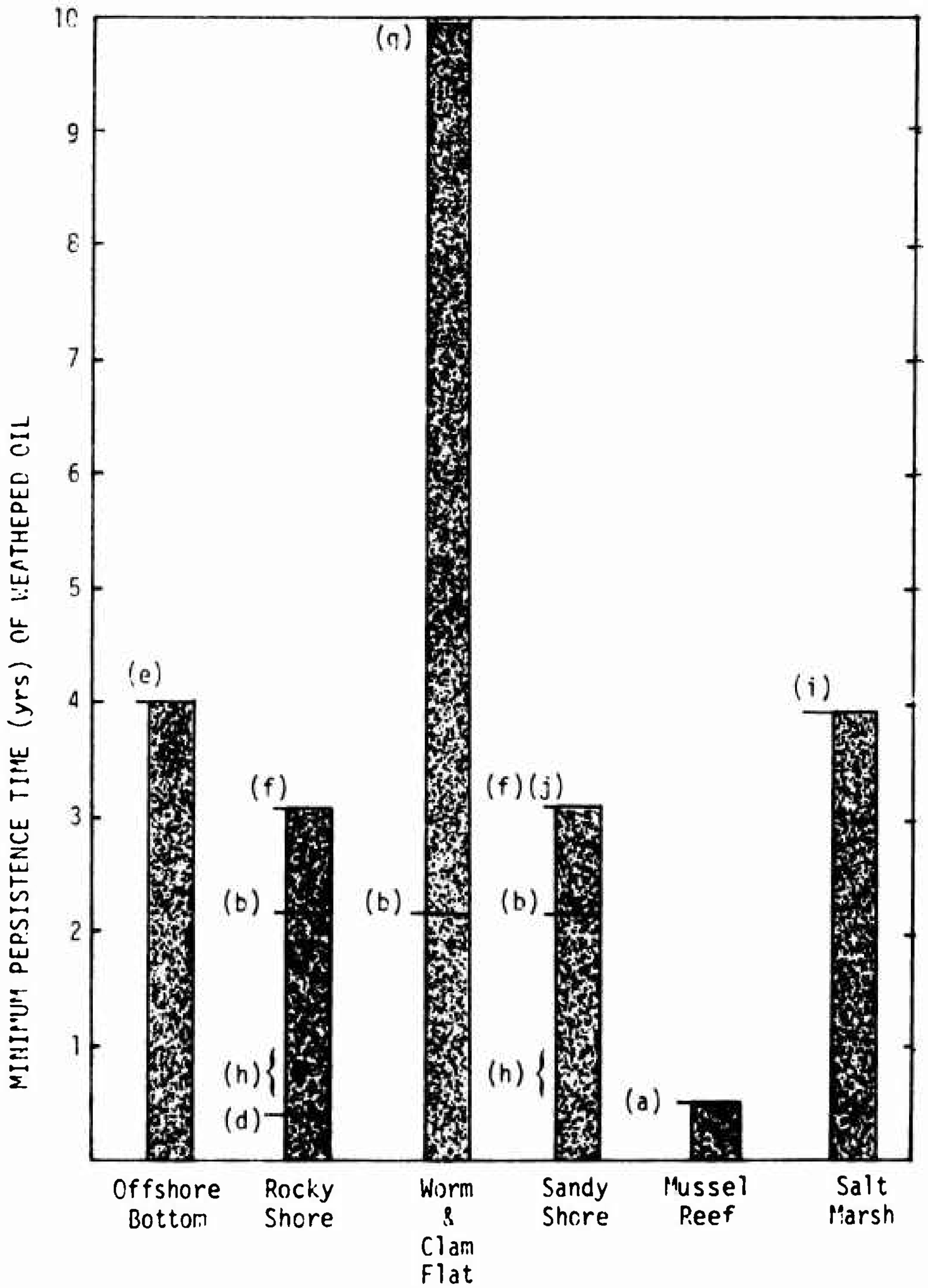


FIGURE 4-1. Observed persistence of petroleum substances in various marine habitats following actual oil spills. Maximum times shown do not necessarily imply complete removal of oil, but may represent author's estimate of persistence or termination of study. See explanatory notes on next page. Source and References for the information are in Reference 6

FIGURE 4-1 (CONT'D)

(a) *Mytilus californianus* were described as having an oil coating after six months; nonlethal effect (Chan, 1973).

(b) Analytical determination of oil (Scarratt and Zitko, 1972).

(c) Author is referring to lagoon, which can be broadly interpreted as a salt marsh (Thomas, 1973).

(d) The authors cite visual evidence of oil retained in rocky ledge by false eelgrass for several months (Clark and Finley, 1973).

(e) Author's estimate after two years; analytical methods; used #2 fuel (Blumer and Sass, 1973).

(f) Interpretation from statement made by authors; analytical techniques: crude oil (Straughan, 1973).

(g) Visual observation and analytical. JP-5 and #2 fuel (Shenton, 1973).

(h) Visual observation--emulsifiers used on crude (Smith, 1968).

(i) Teal, 1973).

(j) Gas-liquid chromatography analysis (Spooner, 1971).

See source 6 for references.

of this oil product in distilled water. The studies undertaken by Legore[11] and Rice[12] are forerunners in this area of measuring the true concentration and makeup of oil products in the water of aquatic bioassays of various oil types. Hopefully, this "dose"/"concentration" problem is now resolved and will not be overlooked in future aquatic bioassays.

B. EFFECTS ON FAUNA

Information obtained from the literature concerning the effects of crude oil and refined products on marine and terrestrial organisms is presented in tabular form in Appendix B. This information was extracted from the 1974 CEQ study[7] and other sources. The following section summarizes this information for invertebrates (marine and freshwater) and vertebrates (birds, fishes, and mammals).

(1) INVERTEBRATES

Invertebrate fauna of concern to this study are marine (13 marine sites) and freshwater aquatic invertebrates (four terrestrial sites that lead to river spills). Terrestrial invertebrates exist at these locations, but the spill cases considered do not extensively involve the terrestrial environment except as involves the logistics and deployment of possible cleanup operations. Therefore, terrestrial invertebrates are not included in this discussion of oil effects nor were they considered in the matrix evaluation process.

(a) ZOOPLANKTON

Zooplankton are primarily filter-feeding crustaceans which are located in pelagic (surface) waters. These microscopic animals have mobility but are generally moved by water currents. They often utilize cilia (hair-like structures) for motility and/or feeding.

Many macro-invertebrate species (crabs, clams) and some fish species have an egg and/or larval stage that, during a pelagic period, becomes an important component of the plankton community (both categories: crab larvae and ichthyoplankton--fish eggs/larvae were broken out from the two general plankton groups in the evaluation matrix). Pelagic eggs/larvae of fishes are discussed in a following section. An important aspect of this pelagic invertebrate stage in crab and clam life histories (as well as other marine invertebrate groups) is that these species can be directly damaged by oil products in this stage even though adults may be in deep water or on beaches a safe distance from the actual spill. Also, investigators reported larvae to be 10 to 100 times more sensitive than adults.

Zooplankton, as a group, are felt to be susceptible to damage by oil spills primarily because of their physical location in close proximity to oil on the sea's surface and any related oil-water emulsions. Impacts could be chemical as well as of a physical nature (i.e., oil droplets clogging cilia).

Zooplankton, in general, are thought to be as susceptible as macro-invertebrate larvae to oil products. Certain invertebrate larvae have been bioassayed in the laboratory, often because of man's economic interest in certain species (see Appendix B). Soluble aromatic derivatives (SAD) caused lethal toxicity at levels of 0.1 to 1 ppm. Death may occur at even lower concentrations if larvae develop abnormally and become more susceptible to predation, competition, or other secondary effects.[13] Mortalities could also result if zooplankton and/or larvae suffer narcotization to reduce ciliar activity as observed in mollusks.[11]

Zooplankton are dependent on a phytoplankton base in the food web so that oil effects on phytoplankton would also impact zooplankton. Phytoplankton seem to be variably impacted with some species sensitive to 1-ppm soluble aromatic derivatives (SAD).[7] The CEQ report[7] went on to say that other species were unharmed by 100 ppm and higher concentrations.

Zooplankton may also concentrate (accumulate) certain petroleum hydrocarbons, the most important of which are carcinogenic compounds (in oil products), and pass them on in the food web as well as deposit the materials to the bottom in fecal pellets.[14]

For the purposes of this investigation, MSNW assumed that zooplankton, including invertebrate crab and other larvae, were very sensitive to oil products such as diesel with high quantities of soluble aromatics and slightly less sensitive to the other oil products such as crude oil or bunker C.

(b) PELAGIC INVERTEBRATES

The only pelagic macro-invertebrates in Alaska that are involved in major food chains are the squids. One source[15] indicated that direct effects are not known, but oil could possibly affect their food supply. This lack of information and lack of squid abundance information for the 13 marine locations precluded consideration of these animals in the evaluation matrix.

(c) BENTHIC MACRO-INVERTEBRATES

Benthic macro-invertebrates are animals that live a portion of their lives on or near the sea floor and below the lowest tide level (contrasted with intertidal macro-invertebrates, following section). This group contains a great variety of animals, some of which are of great economic importance in the State of Alaska (crab species, shrimp). The benthic invertebrates discussed are crustaceans (crabs, shrimp), bivalves (clams, scallops), and other benthic invertebrates (snails, etc.)

Crustaceans are the important commercially-utilized group of benthic invertebrates in Alaska. King crab, tanner crab, Dungeness crab, and numerous shrimp species constitute important fisheries in Alaska (see location descriptions in Section 2).

Benthic crustaceans that are commercially important are primarily deepwater forms as adults. They are assumed to be relatively invulnerable to oil.[14] However, several factors point to greater vulnerability:

1. Oil products (residual products and weathered crudes and refined products) can settle to the bottom and become part of these crustaceans' habitats.

2. Some forms (shrimp) are known to make vertical migrations toward the surface at night, increasing their proximity to oil products and their vulnerability to the oil.

3. The three crab (king, tanner, and Dungeness) move to shallower waters to molt and breed. Vulnerability to oil products would seem greater for the shallower water inhabitant, such as the Dungeness crab, as compared to the deeper water-inhabiting king and tanner crabs.

4. Eggs are carried by the female in these crustaceans for up to a year concentrating these eggs with the female crab. The larvae that hatch from these eggs become pelagic for a period of time. Dungeness and tanner crab larvae reach the surface (pelagic) regions, increasing their vulnerability, while the king crab larvae remain in mid-water and deeper regions.

The vulnerability of crabs and shrimp is therefore thought to be fairly high, with levels of sensitivity ranging from high (larvae, night shrimp migrations), medium (shallower water movements for breeding), and low (deepwater adults, such as king and tanner crabs). Vulnerability is also increased when one considers that slight amounts of oil can taint shellfish and reduce their marketability. This latter factor was not included in this evaluation as it is not an apparent biological impact that is necessarily damaging to the organism.

One source[16] reported bioassay results of Prudhoe crude oil on juvenile tanner crabs as follows:

1. Median tolerance limits for 48 hours for both premolt and postmolt tanner crabs was estimated to be 0.56 ml oil/liter.
2. Molting success of premolt crabs after exposure to 0.32 ml oil/liter was significantly lower than molting success of control crabs.
3. Observations of autotomy in recently molted crabs that survived acute oil exposures suggested that delayed and indirect mortality may occur among crabs that survive a short exposure to oil.

See Appendix B for further data on crustacean larvae and adults.

For the purposes of this evaluation, MSNW assumed a relatively high level of sensitivity for these benthic crustaceans because of the sensitivity of their larvae and the probable vulnerability of migrating adults. No documented impacts on these benthic crustaceans have been noted during Cook Inlet's oil exploration and production periods.

Bivalves in the benthic environment include species of scallops, subtidal razor clams (as exist on the Washington coast), and other bivalve mollusks. Alaska scallops prefer waters deeper than 60 m, thus they are assumed to be low in vulnerability.[14] Legore[11] provided a detailed literature review on the effects of petroleum hydrocarbons on mollusks. Appendix B presents the available literature on bivalves.

As with benthic crustaceans, the pelagic larval stage may increase the vulnerability of mollusks to oil products. One source[15] indicated a relatively low resistance of mollusks to the toxic effects of oil. Acute toxicity is only a part of the impact possible. Some mollusks (*lamellibranches*) have been shown to have reduced pumping rates,[11] probably due to narcotization of cilia. These are cilia-mucous feeders and such impact would reduce food intake and possibly cause a delayed mortality.

As with benthic crustaceans, MSNW ascribed a conservative (moderately high) sensitivity of benthic bivalves to some oil products in this evaluation. Some bivalves do have the protection of closing their shells, but this status cannot be maintained indefinitely.[13] Critical concentrations reported in the CEQ report[7] are 5 to 50 ppm of soluble aromatic derivatives.

Other benthic organisms (small crustaceans, gastropods, etc.) are fairly sensitive to soluble aromatic derivatives (thresholds appear to be 1 to 10 ppm).[13] Therefore, MSNW assumed this miscellaneous group important in food webs (particularly of fishes) as very sensitive to some oil products.

(d) INTERTIDAL MACRO-INVERTEBRATES

Intertidal macro-invertebrates are animals which live on shore zones exposed by tides, from the lowest tide level to the highest tide level. Most of the benthic macro-invertebrate groups are also represented in the intertidal zone; however, the dominants shift from benthic crustaceans to intertidal mollusks. The large razor clam populations in Cook Inlet are an example.

It would be repetitious to restate the prior sections' information for these invertebrates. One dramatic difference between the intertidal macro-invertebrates and their benthic counterparts is that tidal changes expose them to the physical coating of the oil products. A compensating factor is that many intertidal invertebrates have the ability to "seal" themselves within their shell(s) as they do when low tides expose them to the air. The value of this compensation would decline with the time that the oil products would remain in the intertidal area. These organisms can only sustain themselves for limited periods without reexposure to the sea and food resources.

Intertidal macro-invertebrates are much hardier generally as compared to their subtidal counterparts which live in a more constant environment.

MIT[15] reported highly variable results for intertidal macro-invertebrates. Bivalve and some gastropod mollusks' susceptibility appears low while other gastropods such as limpets have a high susceptibility, even at low oil concentrations.[14]

An important bivalve mollusk, the razor clam, was observed to be vulnerable to oil spills. On the Washington coast in 1964, a barge spilled a gasoline/diesel oil mixture on a razor clam beach,[17] resulting in 50 percent mortalities within one-half mile of the site and spotty mortalities (as indicated by numbers of dead clams) for about 20 miles from the site.[18] A minimal estimate of the kill was 300,000 clams.[18]

Any narcotization resulting in behavioral changes in a species could also result in mortality from increased predation on the affected species.

With some conflicting information in intertidal macro-invertebrates and with the importance of razor clams at some Alaska locations, MSNW assumed a high sensitivity for these intertidal animals.

(e) FRESHWATER MACRO-INVERTEBRATES

Freshwater aquatic macro-invertebrates of the streams into which terrestrial oil spills could drain were assumed to be quite sensitive to oil. This has been assumed from the established high sensitivity of small marine crustaceans.

(2) VERTEBRATES

The major vertebrates of concern in this study are probably the marine birds and fishes in the 13 of 17 sites. Marine mammals are also important. On the four terrestrial sites, large terrestrial mammals and freshwater aquatic organisms, including waterfowl, are thought to be the important resources. MSNW has hypothesized terrestrial oil spills that cover only a small amount of land before entering nearby rivers (Colville, Sagavanirktok, Yukon, and Delta). Therefore, the primary resources involved in direct oil impacts on land are those large mammals, the avifauna, and the true aquatic vertebrates associated with these river systems which will receive the terrestrial oil spills.

The following discussion characterizes oil impacts on fishes, birds, and mammals. Specific marine, freshwater, or terrestrial situations are discussed within the general categories for each group of organisms.

(a) FISH

MIT[13] defined three mechanisms by which oil can impact fish. These are:

1. Egg and/or larval mortality on spawning and/or nursery grounds. Eggs and larvae may be affected by concentrations of soluble aromatic hydrocarbons in excess of 0.01 ppm.

2. Adult mortality or failure to reach spawning grounds if the spill occurs in a confined, narrow or shallow waterway necessary for migration or spawning. [Anadromous fish crowding into an estuary would seem especially vulnerable to this hypothetical disaster.]

3. Loss of a local breeding population or ability to breed due to contamination of spawning grounds or the destruction of the nursery area by oil.

The report did not document instances of the second and third mechanisms and impact of these types must by hypothesized at this time.

For the first impact mechanism, MIT[13] indicated the degree of impact on eggs/larvae would depend upon:

1. Time of year of spill and season and duration of spawning.

2. Degree of aggregation of eggs and larvae.

3. Type of eggs and larvae.

Sources[13,16] go further to conclude that little is known about oil impacts of fish species and populations of fish species.

Appendix B summarizes the literature located on oil impacts related to finfish.

SALMONIDS

All of the of salmonids were considered similar in this examination of direct oil effects even though experimental information only exists for Alaskan sockeye, coho,[19,20] and pink salmon,[21] and Dolly Varden.[12] The behavioral differences and presence of these salmonids at a given location determine whether they come into contact with the hypothetical oil spills analyzed in this study. Salmon are generally found in shallow habitats[22] or in surface pelagic waters and could be affected by toxic soluble components in the water column.

Morrow,[19,20] working with juvenile coho and sockeye salmon, concluded:

1. Crude oil poured on the water surface of 25-gallon tanks in amounts equivalent to 500 to 3,000 ppm produced up to 100 percent average mortalities in 96 hours. These quantities of oil might well occur if oil from a spill were carried into shallow inshore waters.

2. The majority of the 96-hour experimental mortality rates are significantly higher than the mortality rates of control animals.

3. The mortality rates are directly related to the concentration of oil, but they appear to be inversely related to water temperature.

4. Mortality apparently is caused by some component of crude oil that is soluble in water and is also volatile and/or easily oxidized.

5. Crude oil loses its toxicity to salmon after exposure to air, probably through the loss of volatile toxic components. Hence, conclusions based on bioassay work with oil of unknown history may be less valuable than those derived from studies wherein the handling history of the oil is known.

Rice,[21] working with pink salmon fry subjected to Prudhoe crude, concluded:

1. Bioassays indicate that older pink salmon fry held in sea water at high temperatures are more susceptible to oil toxicity than younger fry held at lower temperatures.

2. Laboratory avoidance experiments show that pink salmon fry are able to detect low sublethal concentrations of oil.

3. It is not known what the effect of sublethal concentrations of oil on salmon migrations will be, but the potential for harm is clear.

From bioassays on pink salmon fry and small Dolly Varoen, Rice[12] indicated that Cook Inlet crude was 10 to 20 percent more toxic than Prudhoe crude. He[12] also noted increased ventilation (operculum/gill movement) in pink salmon fry.

Also noted in bioassays of varying salinities was that crude oil soluble components were more soluble in sea water than in fresh water.[12] This could create varying toxicities of a given oil type and volume as a species (such as salmon) moves from fresh to sea water and vice-versa, or as salinities change in an area.

Based upon this limited information, MSNW assumed that salmon, trout, and other salmonids are quite vulnerable (in this study) to spilled petroleum and hydrocarbons. MSNW assumed nonlethal impacts (behavioral changes due to oil avoidance) could occur in bays (Kvichak, Kachemak, and others) and in river systems to upset migration patterns and be detrimental to any salmonids present. This is known to be a conservative approach as others have argued that these species can sense sublethal concentrations and avoid them. MSNW agreed that this is probably true in pelagic open-water situations. MSNW also attempted to establish timing of migration in and out of fresh water where oil damage would probably be most severe.

BENTHIC COMMERCIAL FISHES

This group includes, primarily, the cods, flatfishes, and rockfishes. These are generally all bottom-dwelling species (as adults) living in deep water. During spawning movements, these species may come into shallower waters and often their egg and larval stages are pelagic. Appendix B indicates one study showing plaice (a flatfish) eggs very sensitive to an undefined "oil" in a two-day exposure.

Based upon this limited information, MSNW took a conservative approach to this group of species and assumed some oil products, crude and bunker C, and, in particular, their toxic components could, after weathering or after sufficient mixing, reach benthic habitats and the adults of these species. Even with the approach, MSNW assumed only small damage to the adults.

MSNW did assume greater impact where adults of certain species were thought to move into shallow water and where pelagic eggs/larvae were thought to be present. In these cases, greater vulnerability was assumed for these commercial benthic species.

OTHER BENTHIC FISHES

This group includes the numerous sculpin species, greenlings, and other marine fishes. It is impossible to generalize this diverse group concerning the relative impact and their vulnerability. Sculpins occur over a wide depth range as does the remaining mixture of "other" marine fishes (i.e., poachers, lumpsuckers, etc.). The greenlings usually inhabit the shallow waters. As concluded by AEIDC,[22] any "species living in shallow water, either permanently or during a shallow-water stage of its life cycle, could be susceptible." Therefore, MSNW assumed if these species or groups of species met these criterion, then they were moderately vulnerable to oil spills.

PELAGIC FISHES

This group includes herring, smelt, sandlance, and Atka mackeral (a greenling). As pelagic implies, all these species are primarily surface-water dwellers. Herring are especially vulnerable as they deposit adhesive eggs on nearshore kelp, and some sources[14,23] feel a spill would be disastrous to this species. Some smelt species are anadromous like salmon and ascend streams to spawn while others spawn in shallow marine areas adjacent to sand or cobble beaches. Sandlance also spawn similarly to this latter group of smelt. Atka mackeral spawn in shallow cobble-bottom areas with adhesive eggs. Larvae move to the pelagic areas and become adults.

Vulnerability in all these species increases as they move to these shallow shore areas to spawn there or ascend coastal rivers.[23] They are also vulnerable as surface-dwelling adults and larvae. MSNW assumed this group of fish species to be highly vulnerable to oil products, particularly diesel 2, gasoline (while it remains on water), and crude oils with high quantities of soluble aromatics.

FRESHWATER FISHES

These species include some groups already discussed that are marine and anadromous (salmonids). Sculpins, pike, and sticklebacks are examples of other freshwater fishes. Additional salmonids include cisco, whitefish, and grayling.

Hypothetical oil spills from land into rivers (Colville, Sagavanirktok, Yukon, and Delta) were all given by the USCG as being crude oil in varying volumes. Because of the concentrated impact of these spills on restricted areas, MSNW assumed that crude oil was damaging to these species. Behavioral changes resulting from sensing sublethal concentrations were also assumed detrimental to migrating species like some salmonids.

MSNW generally assumed the salmonids, including whitefishes, grayling, and cisco, were similarly very sensitive, particularly as eggs and juveniles. Pike, sculpins, and sticklebacks were assumed to be somewhat less sensitive. Known areas of concentrations of fishes while spawning were also assumed to be extremely vulnerable to crude oil spills.

BIRDS

The greatest observed impact of past oil spills has been on surface-living seabirds. One study[14] summarized the effects of oil on birds as follows:

> Oil mats their feathers, reducing their buoyancy and insulation ability. Not only is the affected bird dulled and hindered, but it may, while preening, injest some oil and be subject to toxic qualities. Birds cannot recognize oil spills and avoid the danger. Birds whose habits bring them into closest contact with oil would be most susceptible.

Table 4-1 provides summary evaluations of susceptible time periods of various bird groups and other flora and fauna to oil spills.

One study[14] summarizes oil effects on bird groups as follows:

BLACK BRANT AND EMPEROR GEESE. These are entirely marine feeders and would be highly vulnerable to losses from the mechanical effects of oil.

CANADA GEESE AND PUDDLE DUCKS. To the extent that these species are less oriented to marine habitats, they would be less susceptible than emperor geese and brant.

DIVING DUCKS. They nest in fresh water. They would be most vulnerable in Fall, Winter, and early Spring when they are on salt water.

SEA DUCKS. Except for nesting of scoters and the harlequin duck, sea ducks are entirely maritime in habit and would be vulnerable most of the year. The greatest numbers of these birds would be in the study area during Spring and Fall migration.

MERGANSERS, LOONS, AND GREBES. These species nest on fresh water and Winter on salt water. Their vulnerability would be similar to that of the diving ducks.

ALBATROSSES. These birds are found in the Western Gulf in Summer and could become trapped in any oil spilled in their feeding areas, particularly tide rips, where both spilled oil and birds tend to concentrate.

TUBENOSES AND STORM PETRELS. These birds are totally marine feeders and would be highly susceptible to mortality from oil.

CORMORANTS. Although the double-crested cormorants sometimes nest in fresh water, the two other cormorant species found in Alaska nest adjacent to marine habitats. In Winter, all feed on exposed open water and could be caught in spilled oil during that period.

OYSTERCATCHERS AND SHOREBIRDS. Birds of this group feed in the intertidal zone and could be effected by oil washing ashore.

JAEGERS. All the jaegers are associated with salt water, the parasitic and pomarize jaeger more so than the long-tailed which nests inland. These birds do not feed on the water but could come in contact with food contaminated by oil. Their risk of exposure to oil is not as high as marine feeders.

TABLE 4-1. SUSCEPTIBILITY OF BRISTOL BAY MARINE ORGANISMS TO INJURY FROM CRUDE OIL

BIOTIC GROUP	HABITAT	AREAS OF PEAK ABUNDANCE	SEASON OF PEAK ABUNDANCE	VULNERABILITY TO DAMAGE BY CRUDE OIL (by month) J F M A M J J A S O N D	REMARKS	[illegible]
Marine Bacteria	Pelagic. Surface to 100 m. Most less than 10 m.	Close to estuaries	?			
Phytoplankton - Diatoms predominant	General. Highest concentration in areas of upwelling and bottom surface of sea ice	Lagoons and estuaries. Offshore in summer	April - October		Speculative and not highly probable	[illegible]
Zooplankton and Micronekton	Pelagic	Inshore waters near Unimak Island and offshore waters near Cape Peirce. In outer Bay.	June through September			[illegible]
Marine Macrophytes	Lagoons and protected bays. Intertidal to 20 m. Eelgrass on muddy sediments of protected bays	Izembeck Lagoon	Growing season		Speculative	[illegible]
Intertidal fauna - including clams	Intertidal or subtidal. Clams on sandy beaches	Throughout	Yearlong		Mortality low unless contamination severe	[illegible]
Clam Adults	Intertidal or subtidal. Various substrates, depending on species	Razor clams on Western Alaska Peninsula. Soft shell clams on north coast.	Yearlong		Vulnerability moderate	[illegible]
Clam Larvae	Shallows		July - November		Vulnerability low	[illegible]
Benthic Invertebrates	From shallow sandy bottoms to 100 m. Variable	Scarce. Density highest on periphery of bay	Yearlong			[illegible]
King Crab - Adults	Shallows. Males concentrate at 100 m. shallower waters in spring	Inshore, east of Unimak Pass. Summer concentrations in center of Bristol Bay	Summer concentrations		Low probability of impact except in shallows	
King Crab - Spawning	Subtidal to 160 m.	Inshore, east of Unimak Pass. Summer concentrations in center of Bristol Bay	April - May		Vulnerability low owing to habitat	
King Crab - Immature	Inshore shallows	Inshore, east of Unimak Pass. Summer concentrations in center of Bristol Bay				
King Crab - Larvae	Semi-pelagic to benthic	Inshore, east of Unimak Pass. Summer concentrations in center of Bristol Bay	Semi-pelagic, May-July			
Tanner Crab - Adults	Generally concentrate at 55-20 m. depth or less	West of 163° W. Long. and at center of Bay				
Tanner Crab - Spawning		West of 163° W. Long. and at center of Bay	January - mid May		Low probability of impact at deep water	
Tanner Crab - Larvae	Semi-pelagic to benthic	West of 163° W. Long. and at center of Bay	Semi-pelagic January - July			
Dungeness Crab - Adults		Scarce in Bristol Bay				
Dungeness Crab - Spawning	Shallows	Scarce in Bristol Bay			Habitat and vulnerability unknown in Bristol Bay	
Dungeness Crab - Larvae	Semi-pelagic to benthic	Scarce in Bristol Bay	Semi-pelagic, January - July			
Shrimp (5 species) - Adults	Variable depths. Daily vertical migration. All rare in Bristol Bay. All occur on NW side of Unimak Is.	Scarce in Bristol Bay			Low probability of impact in deep water	[illegible]
Shrimp - Spawning		Scarce in Bristol Bay				
Shrimp - Larvae	Semi-pelagic and benthic	Scarce in Bristol Bay	Free swimming larvae			
Scallops - Adults	Few in Bristol Bay	Scarce in Bristol Bay				
Scallops - Larvae	Planktonic	Scarce in Bristol Bay			Probably too deep for [illegible]	
Pelagic Invertebrates - Squid	None reported as significant	Unknown	June and July			
Fish - non-commercial (16 families)	Varied habitats and depths	Varied	Unknown			
Pollock - Adults	45-110 m. depth or deeper	Outer Bristol Bay and north side of Alaska Peninsula	Yearlong		Variable exposure, depending on habits	[illegible]
Pollock - Spawning	50-200 m. depth	northwest of Unimak			Deep water, no exposure	
Pacific Cod	55-90 m. or more. Spawn at 100-250 m. Eggs sink to bottom	South of Cape Newenham. Offshore in winter	March - May		Pelagic eggs	
Black Cod	165-730 m. depth. Not in Bristol Bay	Not in Bristol Bay	Not in study area		Deep water. Low probability of impact	
Herring - Adults	Surface to 70 m. depth late spring - early autumn. Offshore in winter. Spawn along shore	Shores of Bristol Bay. Kulukak Point to Togiak. Hagemeister Island. Shallows near Port Moller	Present in study area April - October. Spawn May & June		Eggs and larvae [illegible] at surface	
Herring - Larvae			Planktonic larvae		Damage to kelp would reduce spawning habitat	
Pacific Ocean Perch	145-470 m. depth along rocky bottoms	Edge of continental shelf west of the study area			Deep water. Low probability of impact	
Pacific Ocean Perch - Larvae	Pelagic in cooler, shallower waters for 2 or more years					
Flatfish (excluding Halibut)	Deep waters. Eggs of some may be pelagic	General distribution			Deep water. Low probability of impact except eggs of some species [illegible]	
Halibut - Adults	More than 90 m. deep	Winter west of study area. Migrate east of study area in spring			Low probability of impact in deep water	
Halibut - Eggs and Larvae	Migratory eggs and larvae	North of Unimak Island	November - February		Eggs and larvae [illegible] mid-depths	

SOURCE: Arctic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT--A BACKGROUND STUDY*, c.f. available knowledge, prepared for the Department of the Army, Alaska District Corps of Engineers, February, 1972.

TABLE 4-1. (CONT'D.)

BIOTIC GROUP	HABITAT	AREAS OF PEAK ABUNDANCE	SEASON OF PEAK ABUNDANCE	VULNERABILITY TO DAMAGE BY CRUDE OIL (by month) J F M A M J J A S O N D	REMARKS	SOURCE
Chinook Salmon - Adults	Shallow waters	Bear River, Izembek Lagoon streams, Nelson Lagoon, Port Heiden, Nushagak, Naknek and Togiak Rivers	June		Possible interference with migration	Rice 1977
Chinook Salmon - Immatures	2-4 years. Feed on small fish and crustaceans	Unknown	Unknown		Exposure uncertain	
Coho Salmon - Adults		Togiak, Nushagak and Ilnik Rivers, Port Heiden and Nelson Lagoon	August		Possible interference with migration	Rice 1977
Coho Salmon - Immatures	1-2 years. Feed on small fish and crustaceans	Unknown	Unknown		Exposure uncertain	
Chum Salmon - Adults		Togiak, Nushagak, Kvichak Rivers, Port Moller, Nelson Lagoon, and Izembek and Bechevin Bays	June and July		Possible interference with migration	Rice 1977
Chum Salmon - Immatures	4 years. Feed on small crustaceans		Unknown		Exposure uncertain	
Pink Salmon - Adults		Even years - Togiak, Nushagak, Kvichak Rivers Odd years - Bechevin Bay more important	Late June, early July		Possible interference with migration	Rice 1977
Pink Salmon - Immatures	1½ years. Feed on planktonic crustaceans		Unknown		Exposure uncertain	
Sockeye Salmon - Adults		Immigration offshore. Spawn mainly in Wood, Kvichak, Naknek, Egegik, Bear Rivers and Nelson Lagoon	Late June, early July		Possible interference with migration	Rice 1973
Sockeye Salmon - Immatures	1-4 years. Feed on planktonic crustaceans	Migrate slightly offshore of North Peninsula	Outmigration in mid-May - mid July		Smolts migrate at surface	Straty 1973
Trout and Char	Rainbow rarely in salt water in Bristol Bay	Char widespread, particularly in Togiak, Nushagak and Ugashik Rivers	Overwinter in fresh water		Exposure uncertain	
Black Brant	Bays with eelgrass and other vegetation. Marine feeders	Lagoons on North Peninsula, especially Izembek	Autumn, Spring		No data to adequately assess possible habitat damage	
Emperor Geese	Bays with eelgrass and other vegetation. Marine feeders	Lagoons on North Peninsula, especially Izembek. Winter in Aleutians and Western Peninsula	Autumn, Winter		No data to adequately assess possible habitat damage	
Canada Geese	Occasionally along coastal beaches	Numerous throughout	Autumn, Spring		No data to adequately assess possible habitat damage	
Puddle Ducks (mallard, teal, pintails, baldpates)	Bays, marshes, river mouths. Sometimes feed on salmon carcasses	Throughout. Some yearlong	Autumn, Spring		No data to adequately assess possible habitat damage	
Diving Ducks (Scaup)	Bays, shallow protected waters. Marine feeders	Throughout. Some yearlong	Autumn, Spring		No data to adequately assess possible habitat damage	
Sea Ducks (eiders, scoters, old squaws, harlequins)	Bays, estuaries, sometimes unprotected waters. Marine feeders	Throughout. Some yearlong	Autumn, Spring		No data to adequately assess possible habitat damage	
Mergansers	Bays, estuaries. Marine feeders	Throughout. Some yearlong	Yearlong		No data to adequately assess possible habitat damage	
Loons	Bays, estuaries. Marine feeders	Throughout	Fall and winter		No data to adequately assess possible habitat damage	
[illegible]	Bays, estuaries. Marine feeders	Throughout	Fall and winter		No data to adequately assess possible habitat damage	
Albatross	Surface of open ocean and occasionally in [illegible]	Not abundant	Summer		No data to adequately assess possible habitat damage	
[illegible] (Shearwaters, fulmars, petrels)	Channels, passes. Marine feeders	Generally in western part of study area	Summer		No data to adequately assess possible habitat damage	
Storm petrels	Channels, passes. Marine feeders	Unknown	Yearlong		No data to adequately assess possible habitat damage	
Cormorants	Coastal waters. Dive for food. Nest in cliffs	North coast	Yearlong		No data to adequately assess possible habitat damage	
Oystercatchers	Intertidal rocks	Mostly west of Unimak Island	Scarce in study area		No data to adequately assess possible habitat damage	
Shorebirds	Intertidal or marine - mud flats	Throughout	Yearlong		No data to adequately assess possible habitat damage	
Jaegers	Partly marine feeders in open waters	Throughout	Yearlong		No data to adequately assess possible habitat damage	
Gulls and Terns	Colonial nesters, partly marine feeders	Throughout	Some yearlong		No data to adequately assess possible habitat damage	
Auks, murres, puffins	Colonial nesters, totally marine feeders in open waters	Throughout	Most yearlong		No data to adequately assess possible habitat damage	
Sea Otters	Offshore reefs and kelp beds to 75 m. depth	Southern shore of Bristol Bay from Port Moller west	Peak pupping April - June		Significant matting of fur eliminates insulation	Kenyon 1970
Steller Sea Lion	Along coast, rocky habitat. Winter in shelf and bays and river mouths	Shifting population centers. Disperse in winter. Northwest and southwest portions of Bay	Pupping in June		Susceptibility appears slight	Straughan 1971
Northern Fur Seal	Sometimes in outer Bristol Bay	Occasional only	Spring, summer & fall		Exposure uncertain	
Harbor Seal	Shallow water to 55 m. Sandbars and beaches	Southern coast of Bay	Pupping late May to early June		Susceptibility appears slight	
Walrus	Edge of ice pack	Walrus Island, Hagemeister Island and Amak Island	Summer & fall		Susceptibility appears slight	
Toothed Whales	Mostly offshore	Unknown	Unknown		Susceptibility appears slight	
Baleen Whales	Mostly offshore	Unknown	Unknown		Susceptibility appears slight	

Key to Effects:

- Lethal toxicity
- Sublethal disruption of physiological and behavioral activities
- Effects of direct coating by oil
- Incorporation of hydrocarbons in organisms which cause tainting and/or accumulation of hydrocarbons in food
- Changes in biological habitats

GULLS AND TERNS. Birds of these groups that nest in colonies adjacent to salt water or that Winter on salt water would be highly vulnerable to oil pollution.

AUKS, MURRES, AND PUFFINS. These birds spend all their time in or on salt water except for periods that they are engaged in nesting activities. This group is probably the most susceptible of all birds to losses from oil.

In general, MSNW assumed aquatic birds to be relatively sensitive to all oil products if they were thought to be in an area when a spill occurred, with some groups more susceptible than others as described. The possibility of damage to the food web of many of these birds was also assumed to be high.

Terrestrial birds, including the raptors, ptarmigan, and smaller birds, were thought less susceptible to oil products than the aquatic birds, although they could be affected.

MARINE MAMMALS

Marine mammals include the whales, seals, sea otters, walrus, porpoises, sea lions, and polar bear.

Evidence of direct effects of oil on marine mammals is limited to sea otters, with little evidence of direct impacts on other species.[23] Northern Fur seals were assumed to be vulnerable. Burns[24] also indicated that hair seals (ringed, ribbon, bearded, and harbor) are also possibly impacted by oil spills. The young of these hair seals (less than one month old) are assumed vulnerable while in the "lanugo" (fur) coat. MSNW assumed that oil products in seal haul-out areas or areas of concentration were detrimental. It was also assumed by MSNW that oil products could be damaging to the food chains of these marine mammals.

MSNW basically assumed that sea otters were very sensitive and vulnerable to oil spills and that the other marine mammals were vulnerable only if oil products went to areas of known high concentration of seals and sea lions. This latter impact was assumed to be small. Marine mammals whose food web links were possibly impacted by oil spills were consequently assumed to be slightly impacted by oil spills.

No information was located showing direct oil sensitivities of porpoises, whales, walrus, or polar bear. All could be potentially impacted indirectly through their food webs.

TERRESTRIAL MAMMALS

This group of mammals includes the large carnivores (bears), herbivores (moose, caribou, etc.) to the smaller mammals ("other mammals") such as fox. One source[14] indicated that a large number of these mammals such as mink, weasel, river otter, fox, muskrat, beaver, deer, bear, could be exposed to oil either directly or through their food. The Arctic Environmental Information and Data Center[14] went on to say that direct impacts would not be expected to be severe, but habitat damage could be significant. Storm and high tide combinations could drive oil onto coastal marshes and beaches and would be expected to cause losses in groups such as puddle ducks and shorebirds[22] and possibly terrestrial mammals located there. Terrestrial species that contact coastal marine areas to live and/or feed could also be affected.[14]

River spills in Winter may be important in the land spill sites as moose concentrate in the riparian vegetation along stream courses (possibly 95 percent are within one-half mile of the stream).[25] This Winter problem with moose and possibly other terrestrial species is compensated for by the reduced area that crude oil would spread under Winter conditions. River courses are therefore key habitats in Summer as well as Winter, and some spills of great enough magnitude could be a significant impact. Any aquatic mammals (beaver, muskrat, river otter) depending on fur for insulation would also be vulnerable to the physical impacts of oil.

C. EFFECTS ON VEGETATION

(1) MARINE FLORA

Most field studies of the subtidal communities in the area of oil spills have concluded that the subtidal algae are not generally affected.[26 - 30] Only a few subtidal species were observed to be affected by the Torrey Canyon spill which effects might have been due to detergents used to emulsify the oil.[31,32] A great increase in growth of subtidal flora was observed after a diesel oil spill and thought to be due to the mortality of invertebrate grazers in the area.[33]

The greatest negative effects on marine algae from oil spills occur in the intertidal.[26-52] It is clear that there is a great deal of variability in the mortality observed in this region. Some of this variability depends upon the type of flora, substrate, environmental conditions (sea state, temperature, etc.), type of oil and other factors. For example, the ARROW spill (bunker C or #6 fuel) in Nova Scotia (the area most similar phytogeographically to Alaska in which oil spill effects have been studied) showed no significant changes in concentration of algae and no direct toxic effects to mature or juvenile plants (including eelgrass) over a period of two months.[30,39] The heavy algal mortalities observed after the Torrey Canyon spill are generally attributed to detergents.[32,39,41] The more volatile components of the crude oil probably were dissipated before the oil reached the shore, making the oil itself practically harmless.[31] Effects depended upon the precise points at which oil touched the shore (i.e., lee shores were not contacted and not affected).[31]

After intensive study, it was concluded that the mortality of marine algae due to oil was insignificant (or possibly masked) compared to normal agents of mortality such as freshwater runoff and sand movement and other sources of pollution.[34-36,44,52] However, kills of *Phyllospadix* (surf grass) were attributed to the oil.

"Smothering" and consequent mortality were observed to a small and sporadic extent after crude oil spills.[29,34,36,41]

The heaviest mortalities of marine algae were observed where diesel oil was spilled very close to shore and concentrated within a small cove.[33] A similar case was observed off the Washington Coast where oil was again concentrated into a cove by shipwreck.[45]

As previously mentioned, marine algae sometimes exhibit a marked increase in biomass by growth of sporelings when oil spills kill invertebrate grazers that would otherwise keep them cropped down.[31,33,41]

Recovery to normal populations of marine algae is usually fairly fast (one to two years) but depends upon the longevity of oil smears covering rock surfaces and preventing algal settlement[41] and the recovery of algal herbivores.[31,33,41]

The relationships of the major factors and the effects on marine algae are shown in Table 4-2. The worst scenario would be diesel oil spilled directly into a relatively confined embayment where most or all intertidal marine algae would be killed. When any of these factors are changed, effects would be less.

TABLE 4-2. GENERAL RELATIVE EFFECTS OF OIL ON MARINE ALGAE

FACTOR (1)	EFFECTS: LEAST (2)	EFFECTS: MOST (3)
Oil Type	Crude Oil	Highly Refined Oil
Time to Impact	Long Time to Impact	Short Time to Impact
Confinement and/or Quantity	Unconfined, Little Oil	Very Confined, Much Oil
Floral Region	Subtidal Flora	Intertidal Flora

(2) CRUDE OIL IMPACTS ON TERRESTRIAL AND AQUATIC VEGETATION

Numerous studies (accidental and experimental spills) indicated that crude oil and distilled products are toxic to plants.[53] Oil spilled on some vegetation (tundra) is expected to also have physical impacts such as physical coating as well as local heat flux changes. The latter results from the destruction of the stabilizing mat, in addition to increased absorption of solar radiation, which may create increased thaw and permafrost degradation.[54]

Toxicity of crude oil on plants is quite variable depending on the species involved. Distillation products (diesel fuel, jet fuel, auto gasoline, aviation gasoline) were shown to be very toxic to terrestrial vegetation after spills from the Haines-Fairbanks Military Pipeline.[55] This source[55] went on to indicate that numerous tree species were killed, along with lichens, sedges, herbaceous plants, and woody shrubs. The growth was reduced in some trees. How these distilled products relate to the crude oil scenarios in this study is not known, although the toxicity of these distilled products is potentially more destructive than crude oil.[56]

In crude oil experiments, some sedges seemed relatively tolerant; however, reduced production resulted in following growing seasons. Heavy saturations of soil with crude oil or crude oil contacting plant foliage and roots resulted in the death of the plant, particularly in very low-growing plants such as lichens and mosses.[56]

Plant recovery from crude oil impact is adequate if only covered foliage is killed; however, recovery is reduced if soils are penetrated and roots are exposed to oil.[56] This source[56] concluded that plant structure and probable low oil penetration in soil may make the Arctic terrestrial regions relatively less vulnerable to severe damage as compared to terrestrial regions in taiga and temperate areas. If crude oil soil penetration does occur, more extensive damage is expected and impacts would be long term and extend for many seasons.[56] Penetration of oil seems to be a function of water content with dry areas exhibiting penetration to the permafrost while wet areas (assumed at the Onshore Prudhoe and Umiat-Colville River spills) did not allow oil penetration much below the organic layer (less than 1.6 in.).[57]

Terrestrial impact at Onshore Prudhoe and Umiat are expected to be small in the small amount of wet sedge meadow tundra crossed by the hypothetical crude oil spills from the spill site to the receiving river (Sagavanirktok and Colville, respectively). In these rivers, the small amounts of aquatic vegetation, including sedges such as *Carex* and *Eriophorum*, that are assumed to be present in the Summer season are expected to be moderately impacted. Dwarf willows and herbaceous plants are assumed to be moderately to heavily impacted based upon the impact of distilled products on these plants described by one source.[58]

The terrestrial and aquatic plants described for the Yukon River crossing location and the Denali Fault location are assumed to be moderately impacted by any oil reaching these plants. At each location, only a small section of terrestrial area is covered before the oil enters the Yukon River or Castner Creek-Delta River. The oil in the free-flowing Yukon River would be expected to contact aquatic and nearshore riparian vegetation as it was carried downstream. On the Delta River, the same would occur except that much more shoreline and islands could be contacted because of the braided nature of the Delta River stream bed. The Yukon by comparison is a relatively open channel with major islands from the Yukon crossing to the Tanana junction.

Oil impacts on aquatic and terrestrial riparian vegetation would be expected to be greater for similar volumes of crude oil on the Delta River as compared to the Yukon River because of the greater exposure of vegetation to this oil. Also contributing is the much greater flow rate and volumes on the Yukon which would have a diluting effect. Oil on the Yukon would be expected to become involved in small side branches, in back eddies, and in the outside of oxbow-type turns in the stream bed, but this would be scattered over a wide area wherever these conditions and possibly others exist to "collect" crude oil.

Compared to terrestrial impacts which would have a long-term component, the crude oil in these rivers would be expected to have a lower long-term component with the Yukon expected to have the lowest long-term impact of all rivers evaluated.

A scondary impact of crude oil spill that is probable with the men and machinery around the spill sites is the ignition of hydrocarbon vapors produced by the flashing process of hot crude released from a pipeline, if the oil is to be piped at a temperature above $70^{o}C$.[58] Besides the obvious human hazard (fire and possibly toxic concentrations of H_2S), there are environmental hazards from fire, particularly in the Summer. Arctic fires, especially, are well understood to be of severe ecological damage with a long restoration period.[58] These impacts would result from destroying the insulating active layer of moss and melting permafrost which would lead to ground instability, and the residue from burned oil which would modify the local albedo to cause further thermal changes.[58]

D. SUMMARY EFFECTS ON FLORA/FAUNA

Various authors have attempted to summarize oil effects on flora and fauna AEIDC prepared a marine flora/fauna summary (see Table 4-1) for Bristol Bay which is applicable in other marine study areas where these or similar groups or species exist. Timings may vary for sites north and south of Bristol Bay, but the summary is still felt applicable.

Another useful summary was prepared after a literature review. The information from their report is presented in Table 4-3 .

TABLE 4-3 . TOXICITY RANGES OF VARIOUS OIL PRODUCTS ON SEVERAL CLASSES OF ORGANISMS

	ESTIMATED TYPICAL TOXICITY RANGES (PPM) FOR VARIOUS SUBSTANCES			
CLASS OF ORGANISMS (1)	SAD[1] (2)	#2 FUEL OIL/KEROSENE (3)	FRESH CRUDE (4)	WEATHERED CRUDE
Flora	10 - 100	50 - 500	10^4 - 10^5	Coating More Significant than Toxicity
Finfish	5 - 50	25 - 250	10^4 - 10^5	" "
Larvae	0.1 - 1.0	0.5 - 5.0	10^2 - 10^3	" "
Pelagic Crustaceans	1 - 10	5 - 50	10^3 - 10^4	" "
Gastropods	10 - 100	50 - 500	10^4 - 10^5	" "
Bivalves	5 - 50	25 - 250	10^4 - 10^5	" "
Benthic Crustaceans	1 - 10	5 - 50	10^3 - 10^4	" "
Other Benthic Invertebrates	1 - 10	5 - 50	10^3 - 10^4	" "

[1]Soluble aromatic derivatives (aromatics and naphthenoaromatics)

SOURCE: President's Council on Environmental Quality, *OUTER CONTINENTAL SHELF OIL AND GAS--AN ENVIRONMENTAL ASSESSMENT*, April 1974.

The evaluations made in scoring matrix impacts, coupled information as to the presence (and abundance) of species or groups of species, their location in relation to the oil, and the varying sensitivities of these species or groups of species as designated in these two tables.

E. EFFECTS ON THE PHYSICAL ENVIRONMENT

Potential effects on the physical environment range from very small-scale effects such as locally changing the percolation characteristics of a small beach segment[59] (see Section 5-E) to large-scale effects such as altering the albedo[60-62] and, hence, the equilibrium of the Arctic ice pack (Section 5-C-2). The importance of all of the potential effects on the physical environment has not been assessed in any systematic manner nor is there even agreement on the quantities of oil required to cause a measurable physical impact, as in the case of albedo changes of the ice pack.[61,62] Nevertheless, one can single out the albedo effects and the potential alterations of permafrost equilibrium levels[58] as the major physical environment impacts. For both ice and land-based spills, the effects of burning as a means of disposing of spilled oil must be further investigated, since burning by-products may intensify the physical effects of the oil. Certainly on land, where revegetation is a slow process, burning may be more detrimental than the oil itself which may be removed manually as evidenced by the changes in vegetation and permafrost levels in natural fire areas. Whether smoke generated by burning oil on the ice pack causes sufficient distribution of particulate matter to alter ice albedo appreciably or not needs to be investigated in more detail.

The detrimental effects on northern terrain of heavy equipment traffic are well-known and documented.[63] As a consequence, shoreside cleanup activities in the tundra regions are assumed to be water or beach-based.

SECTION 4. REFERENCES

1. Clark, R. B., *OIL POLLUTION AND ITS BIOLOGICAL CONSEQUENCES, A REVIEW OF SCIENTIFIC LITERATURE PREPARED FOR GREAT BARRIER REEF PETROLEUM DRILLING ROYAL COMMISSION*, Department of Zoology, University of Newcastle on Tyne, 31 January 1973.

2. NAS, *BACKGROUND PAPERS FOR WORKSHOP ON INPUTS, FATE, AND EFFECTS OF OIL IN MARINE ENVIRONMENTS*, National Academy of Science, May 21 thru 25, 1973.

3. Nelson-Smith, A., *OIL POLLUTION AND MARINE BIOLOGY*, Plenum Press, N.Y., 1973.

4. Moore, S. F., R. L. Cwyer, and A. M. Katz, *A PRELIMINARY ASSESSMENT OF THE ENVIRONMENTAL VULNERABILITY OF MACHIAS BAY, MAINE, TO OIL SUPERTANKERS*, MIT Laboratory of Water Resources and Hydordynamics, TR 162, 1973.

5. Boesch, D. F., C. H. Hershner, and J. Milfran, *OIL SPILLS AND THE MARINE ENVIRONMENT*, Ballinger Publishing Company, Cambridge, Mass., 1974.

6. Moore, S. F., G. R. Churlin, C. J. Puccia, and B. P. Schrader, *POTENTIAL BIOLOGICAL EFFECTS OF HYPOTHETICAL OIL DISCHARGES IN THE ATLANTIC COAST AND GULF OF ALASKA*, MIT Department of Civil Engineering, Report MITSC 74-19, 1974.

7. President's Council on Environmental Quality, *OUTER CONTINENTAL SHELF OIL AND GAS--AN ENVIRONMENTAL ASSESSMENT*, April 1974.

8. Straughan, D., "Factors Causing Environmental Changes After An Oil Spill," *J. PETROLEUM TECHNOLOGY*, 250-254, March 1972.

9. Brooks, J. W., J. C. Bartonek, D. R. Klein, D. L. Spencer, and A. S. Thayer, *ENVIRONMENTAL INFLUENCES OF OIL AND GAS DEVELOPMENT IN THE ARCTIC SLOPE AND BEAUFORT SEA*, USDI Fish and Wildlife Service, BSF&WS Resource Publication 96, 24 pages, 1971.

10. Blumer, M. and J. Sass, *THE WEST FALMOUTH OIL SPILL II, CHEMISTRY.*, Woodshole Oceanographic Institute, Technical Report WHOI-72-19, April 1972.

11. LeGore, Richard Stephan, *THE EFFECT OF ALASKAN CRUDE OIL AND SELECTED HYDROCARBON COMPOUNDS ON EMBRYONIC DEVELOPMENT OF THE PACIFIC OYSTER, CRASSOSTREA GIGAS*, PhD Thesis, University of Washington, 181 pages and Appendices, 1974.

12. Rice, Stanley, NOAA-NMFS, personal communication, 29 August 1974.

13. Massachusetts Institute of Technology, *POTENTIAL BIOLOGICAL EFFECTS OF HYPOTHETICAL OIL DISCHARGES IN THE ATLANTIC COAST AND GULF OF ALASKA,* U. S. Department of Commerce, BOM-74-11089, April 1974.

14. Arctic Environmental Information and Data Center, *WESTERN GULF OF ALASKA, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE,* Land Management-Offshore Continental Shelf Office, Draft--on microfiche.

15. MIT, *THE GEORGES BANK PETROLEUM STUDY. VOL. II.,* Offshore Oil Task Group, Report No. MITSG 73-5, 1973.

16. Karinen, John F. and Stanley D. Rice, "Effects Of Prudhoe Bay Crude Oil On Molting Tanner Crabs, Chionoecetes Bairdi," *MARINE FISHERIES REVIEW,* Volume 36, No. 7 (paper 1074), July 1974.

17. USDI Bureau of Sport Fish and Wildlife Service, *LOSS OF MARINE LIFE ON PACIFIC BEACHES OF QUINAULT INDIAN RESERVATION AND ADJOINING AREAS, WASHINGTON--INCIDENTIAL TO STRANDING OF PETROLEUM BARGE AT MOCLIPS, MARCH 11 TO 17, 1964,* Special Report, 10 April 1964.

18. Lindsey, C. and H. Tegelberg, *RAZOR CLAM MORTALITIES AT PACIFIC AND COPALIS BEACHES,* Washington State Department of Fisheries, unpublished report, March 1964.

19. Morrow, James, E., "Oil-Induced Mortalities In Juvenile Coho And Sockeye Salmon," *JOURNAL OF MARINE RESEARCH,* Volume 31, Number 3, pages 135-143, 1 May 1973.

20 Morrow, James E., *EFFECTS OF CRUDE OIL AND SOME OF ITS COMPONENTS ON YOUNG COHO AND SOCKEYE SALMON,* Office of Research and Development, U.S. Environmental Protection Agency, EPA-660/3-73-018, January 1974.

21. Rice, S. D., *TOXICITY AND AVOIDANCE TESTS WITH PRUDHOE BAY OIL AND PINK SALMON FRY,* in; "American Petroleum Institute , Environmental Protection Agency and United States Coast Guard, Proceedings Of Joint Conference On Prevention And Control Of Oil Spills," pages 667-680, 1973.

22. Arctic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT--A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE,* Department of the Army, Alaska District, Corps of Engineers, February 1974.

23. Burns, John J. and James E. Morrow, *ARCTIC OIL AND GAS: PROBLEMS AND POSSIBILITIES,* Foundation Francaise D'Etudes Nordiques, Fifth International Congress, Report No., "The Alaskan Arctic Marine Mammals And Fisheries," May 2 thru 5, 1973. Draft manuscript.

24. Burns, John, Alaska Department of Fish and Game, personal communication, 28 August 1974.

25. Burris, Oliver E., Alaska Department of Fish and Game, personal communication, 28 August 1974.

26. Strachan, Alex, "Santa Barbara Oil Spill--Intertidal And Subtidal Surveys," *RPTS., CALIF. COOP. OCEANIC FISH. INVEST.*, 16:122-124, 1972.

27. Sharpe, G., *OBSERVATIONS OF MACRO ALGAE POPULATIONS IN THE OIL-POLLUTED SHORES OF CHEDABUCTO BAY*, Nova Scotia Department of Fish, 1970.

28. Thomas, M. L. H., "Effects Of Bunker C Oil On Intertidal And Lagoonal Organisms In Chedabucto Bay, Nova Scotia," Marine Ecol. Lab. or *J. FISH. RES. BD. CANADA*, 30 (1):83-90, 1973.

29. Bellamy, D. J., et. al., "Effects Of Pollutuion From The Torrey Canyon On Littoral And Sublittoral Ecosystems," *NATURE*, 216: 1170-1173, 1967.

30. Royal Commission on the Steam Tanker "Arrow", Ottawa, Canada, 1971.

31. Smith, J. E. (ed.), *TORREY CANYON, POLLUTION AND MARINE LIFE*, Mar. Biol. Assn., U.K., Cambridge Univ. Press, 188 pages, 1968.

32. Boney, A. D., *EXPERIMENTS WITH SOME DETERGENTS AND CERTAIN INTERTIDAL ALGAE*, in: "Carthy, J. D. and D. Arthur, Bioligical Effects Of Oil Pollution On Littoral Communities," London Field Studies Council, pages 55-71, 1968.

33. North, Wheeler J., M. Neushul and K. Clendenning, *SUCCESSIVE BIOLOGICAL CHANGES OBSERVED IN MARINE COVE EXPOSED TO A LARGE SPILLAGE OF MINERAL OIL*, 1965.

34. Nicholson, Nancy, "The Santa Barbara Oil Spills In Perspective," *RPTS. CALIF. COOP. OCEANIC FISH. INVEST.*, 16:130-149, 1972.

35. Foster, Michael, "The Santa Barbara Oil Spill: Dosage Of Crude Oil On Share And Initial Effects On Intertidal Organisms," *RPTS. CALIF. COOP. OCEANIC FISH. INVEST.*, 16:150, 1972.

36. Nicholson, Nancy L. and R. L. Climberg, *THE SANTA BARBARA OIL SPILLS OF 1969: A POST-SPILL SURVEY OF THE ROCKY INTERTIDAL*, in: "Straughan, D. (ed.), Biological And Oceanographical Survey Of The Santa Barbara Channel Oil Spill. 1969-1970, Vol. 1., Biology and Bacteriology," pages 325-399, 1971.

37. Shorland, F. B. and D. E. Hurley, "Report Of The New Zealand Committee On Problems Of Oil Pollution, And Sandy Beaches And Methods For Its Disposal," *MARINE POLL. BULL.*, No. 15, 31 pages, 1969.

38. Butler, M. J. A. and F. Berkes, *BIOLOGICAL ASPECTS OF OIL POLLUTION IN THE MARINE ENVIRONMENT: A REVIEW*, Mar. Sci. Centre, McGill Univ., Manuscript Rpt. #22, 118 pages + Appendix pages 120-133, 1969.

39. Craigie, J. S. and J. McLachlan, *OBSERVATIONS ON THE LITTORAL ALGAE OF CHEDABUCTO BAY FOLLOWING THE "ARROW" OIL SPILL*, Atlantic Reg. Lab., National Research Council, ARL-8, NRC #11989, 1970.

40. Dalby, D.H., *SOME FACTORS CONTROLLING PLANT GROWTH IN THE INTERTIDAL ENVIRONMENT*, in: "Carthy, J. D. and D. Arthur, Biological Effects Of Oil Pollution On Littoral Communities," London Field Studies Council, No. 2, pages 31-37, 1968.

41. Ranwell, D. S., *EXTENT OF DAMAGE IN COASTAL HABITATS DUE TO THE "TORREY CANYON" INCIDENT*, in: "Carthy, J. D. and D. Arthur, Biological Effects Of Oil Pollution On Littoral Communities," London Field Studies Council, No. 2, pages 39-47, 1968.

42. Bellamy, D. J. and A. Whittick, *PROBLEMS IN THE ASSESSMENT OF THE EFFECTS OF POLLUTION ON INSHORE MARINE ECOSYSTEMS DOMINATED BY ATTACHED MACROPHYTES*, in: "Carthy, J. D. and D. Arthur, Biological Effects Of Oil Pollution On Littoral Communities," London Field Studies Council, No. 2, pages 49-54, 1968.

43. Nelson-Smith, A., *BIOLOGICAL CONSEQUENCES OF OIL POLLUTION AND SHORE CLEANSING*, in: "Carthy, J. D. and D. Arthur, Biological Effects Of Oil Pollution On Littoral Communities," London Field Studies Council, No. 2, pages 73-80, 1968.

44. Cimberg, R., S. Mann, and D. Straughan, *A REINVESTIGATION OF SOUTHERN CALIFORNIA ROCKY INTERTIDAL BEACHES THREE AND ONE-HALF YEARS AFTER THE 1969 SANTA BARBARA OIL SPILL: A PRELIMINARY REPORT*, in: "Proc. Joint Conf. Prevention and Control Of Oil Spills," pages 697-702, 1973.

45. Clark, R. C., J. S. Finley, B. Patten, D. Stefani, and E. DeNike, *INTERAGENCY INVESTIGATIONS OF A PERSISTENT OIL SPILL ON THE WASHINGTON COAST*, in: "Carthy, J. D. and D. Arthur, Biological Effects Of Oil Pollution On Littoral Communities," London Field Studies Council, No. 2, pages 793-808, 1973.

46. Baker, J. M., *BIOLOGICAL EFFECTS OF REFINERY EFFLUENTS*, in: "Carthy, J. D. and D. Arthur, Biological Effects Of Oil Pollution On Littoral Communities," London Field Studies Council, No. 2, pages 715-724, 1973.

47. Shiels, W.E., J. Goering and D. Hood, *CRUDE OIL PHYTOTOXICITY STUDIES*, in: "Hood, D., Shiels, W. and J. Kelly, Environmental Studies of Port Valdez," Institute Mar. Sci., Univ. of Alaska, Occas. Pap. 3, 1973.

48. Rutzler, K. and W. Sterrer, "Oil Pollution Damage Observed In Tropical Communities Along The Atlantic Seaborad Of Panama," *BIOSCIENCE*, 20:222-224, 1970.

49. O'Sullivan, A. J. and A. J. Richardson, "The 'Torrey Canyon' Disaster and Intertidal Marine Life," *NATURE*, 214:448, 541-542, 1967.

50. Schram, W., *THE EFFECTS OF OIL POLLUTION ON GAS EXCHANGE IN PORPHYRA UMBILICALIS WHEN EXPOSED TO AIR*, Proc. 7th Int. Seaweed Symp., pages 309-315, 1972.

51. Clendenning, K. A., *THE EFFECTS OF WASTE DISCHARGES ON KELP: FUEL OIL*, Inst. Mar. Res., Univ. Calif. San Diego, Ref. 59-4, pages 4-12, 1959.

52. Foster, M., M. Neushul and R. Zingmark, "The Santa Barbara Oil Spill Part 2: Initial Effects On Intertidal And Kelp Bed Organisms," *ENVIR. POLL.*, 2:115-134, 1971.

53. United States Department of the Interior, *ENVIRONMENTAL IMPACT STATEMENT--PROPOSED TRANS-ALASKA PIPELINE, VOLUMES I-VI*, Stock Number 2401-2116.

54. McCown, B. H., J. Brown, R. P. Murrmann, *THE IMPACT OF OIL SPILLS ON ARCTIC AND SUBARCTIC TERRESTRIAL ECOSYSTEMS--A LITERATURE SURVEY*, U. S. Army Cold Regions Research and Engineering Laboratory, 14 pages, April 1970.

55. Rickard, W. E. and F. Deneke, *PRELIMINARY INVESTIGATION OF PETROLEUM SPILLAGE, HAINES-FAIRBANKS MILITARY PIPELINE, ALASKA*, U.S. Army, CRREL, Special Report 170, 23 pages, April 1972.

56. McCown, B. H., F. J. Deneke, W. Rickard, and L. L. Tieszen, *THE RESPONSE OF ALASKAN TERRESTRIAL PLANT COMMUNITIES TO THE PRESENCE OF PETROLEUM*, in: "Proceedings Of The Symposium On The Impact Of Oil Resource Development On Northern Plant Communities," Occasional Publications On Northern Life, No. 1, Institute of Arctic Biology, University of Alaska, pages 34-43, August 1972.

57. Hutchinson, T. C. and J. A. Hellebust, *OIL SPILLS AND VEGETATION AT NORMAN WELLS*, Environmental-Social Committee, Northern Pipelines, University of Toronto, NWT Report No. 73-43, 129 pages, January 1974.

58. Mackay, D., M. E. Charles, and C. R. Phillips, *THE PHYSICAL ASPECTS OF CRUDE OIL SPILLS ON NORTHERN TERRAIN*, Environmental-Social Committee, Northern Pipeline, University of Toronto, Report No. 73-42, 213 pages, January 1974.

59. Gebelein, C. D., *SEDIMENTATION PROCESSES INVOLVING HYDROCARBONS IN THE MARINE ENVIRONMENT*, working paper for Ocean Affairs Board Workshop on Inputs, Fates And Effects Of Petroleum in the Marine Environment, May 21 thru 25, 1973.

60. Campbell, W. and S. Martin, "Oil And Ice In The Arctic: Possible Large Scale Interactions," *SCIENCE*, 181, 1973.

61. Ayers, R. C., H. O. Jahns, and J. L. Glaeser, "Oil Spills In The Arctic Ocean: Extent Of Spreading And Possibility Of Large-Scale Thermal Effects," *SCIENCE*, 186, 1974.

62. Martin, S. and W. Campbell, "Reply To Ayers, Et. Al.," *SCIENCE*, 186, 1974.

63. Radforth, J. R., *LONG TERM EFFECTS OF SUMMER TRAFFIC BY TRACKED VEHICLES ON TUNDRA*, Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Report No. 73-22, ALUR 72-73-13, 1973.

SECTION 5. DISPERSION AND FATE OF OIL IN THE ENVIRONMENT

The processes to be considered when evaluating the eventual fate of an oil spill, and hence the associated environmental impact, are:

1. Initial spreading and subsequent transport.
2. Evaporation into the atmosphere.
3. Dissolution into the water column, if a water spill.
4. Absorption by supporting material, if land or fast ice spill.
5. Emulsification, if a water spill.
6. Auto-oxidation (chemical oxidation and/or photo-chemical reaction).
7. Microbial degradation.
8. Sinking or sedimentation, if a water spill.
9. Resurfacing, if a water spill.
10. Leaching, if land-based spill.

Of these processes, the physical and chemical changes undergone by a given oil or oil product as a result of evaporation, dissolution, emulsification, auto-oxidation, and microbial degradation, are collectively called "weathering" or "aging." The remaining processes may be grouped under the collective title of "dispersion." In this section, we will discuss the current state-of-the-art in modelling and predicting dispersion (under certain assumptions) and weathering.

Two basic oil spreading situations can be defined:

1. Spreading of oil on water.
2. Spreading of oil on rough surfaces such as ice or land.

In each case, initial spreading is governed by physical forces followed by migration due to various dispersion mechanisms.

The first step in estimating the environmental effects resulting from postulated oil spills is to identify impacted locations and biota. This in turn requires one to predict oil spill dispersion on land and water bodies (surface dispersion) based on known or estimated environmental and topological conditions. Computerized models of spill spreading and migration are frequently used to analyze spills because of the complexities introduced by a multiplicity of possible spill scenarios, variations in topography, and current and wind patterns. The specific method of analysis will depend upon the characteristics of the particular potential spill. The following classification of environmental and topological conditions is useful for discussing the present state-of-the-art of oil dispersion modelling:

1. Open water, moderate seas, currents, and wind.
2. Fast ice, with or without leads.
3. Terrestrial spill, no snow or ice cover.
4. Terrestrial spill, snow and/or ice cover.
5. Terrestrial spill, reaching flowing river or stream, ice-free.
6. Moving pack or floe ice in open seas.
7. Open water, storm conditions.
8. Open water, storm conditions and strong currents.
9. Ice pack breakup under storm conditions.
10. Terrestrial spill, reaching river or stream during ice breakup.

Almost all modelling efforts reported in the literature to date have concentrated on Class (1)--the prediction of spreading and dispersion of oil slicks on open water with moderate wind and current conditions prevailing. Recently, progress has been made in modelling the spread of oil on fast ice, with or without open leads, (2). The results of these studies may be applicable to various classes of terrestrial spills (3), (4), with suitable modifications, and, by considering the modelling of oil flow in a channel, extended to include Class (5). Class (6) may be included in the known results of Class (1) by suitable modifications to account for ice movements.

No substantial theories are known at this time for the remaining classes (7) through (10), all of which are characterized by the possibility of violent mixing mechanisms. The general path of impacted water and/or ice-water mixtures may be reasonably estimated by application of the models developed for Class (1); however, the time history of the pollutant movement can only be estimated presently. Furthermore, determination of the vertical mixing regions (other than what are defined for simple vertical diffusion models), as well as estimation of the amount of oil or oil fractions which will remain in underlying surfaces (river beds, shallow-water bottomlands, shorelines, etc.), is not possible within the present state-of-the-art.

In addition to defining the surface area impacted by dispersing oil, one must also estimate the vertical movement of oil fractions and define the physical and chemical characteristics of oil as a function of time. As noted above, vertical dispersion at the present time is taken into account via a simple diffusion model. The change of chemical and physical characteristics with time--collectively termed "weathering"--was investigated to a limited extent; the state-of-the-art of both vertical diffusion and weathering modelling is discussed in more detail in Sections D and E.

A. PREDICTION OF OIL SLICK MOTIONS ON WATER

Prediction of oil slick motions on the surface of moderately quiescent water incorporates the calculation of oil slick spreading and subsequent drift motion as determined by wind, waves, and surface currents.

(1) OIL SLICK SPREADING ANALYSIS

At the present time, there are two basic approaches to the calculation of the physical spread of oil on water. The first is an empirical one, proposed by Blokker,[1] based upon the assumption that the spreading rate decreases exponentially with the reduction of slick thickness.

$$kt = \frac{\pi(R^3-R_i^3)\rho_w}{3V(\rho_w-\rho_o)\rho_o} \tag{5-1}$$

where

k = the Blokker constant

t = spreading time in seconds

V = volume of oil in the slick in cm^3

ρ_w, ρ_o = the densities of water and oil

R, R_i = radius of the slick (R_i the initial base radius) in cm.

The underlying assumption to Equation 5-1 is that oil spreads in a uniform fashion forming a circular patch.

An attempt to experimentally validate Equation 5-1 via specially discharged oil slicks on the open ocean is reported by Jeffrey.[2] The results of the experiments are inconclusive, as the Blokker constant varied from 117 to 360 with no apparent pattern. Although the empirical relationship has appealing simplicity, it was considered to be insufficiently validated to be used in a spill dispersion model.

The second approach, as developed by Fay and Hoult[3,4] and Fannelop and Waldman,[5,6] treats oil as a fluid of homogeneous density, viscosity, and surface tension. These assumptions neglect the differential spreading effects of components of a particular crude or oil product. Some components of a particular oil will spread considerably faster than the bulk of the oil; a peripheral flash of crude oil moving well ahead of the bulk has been observed at some oil spill incidents; however, no quantitative measure of this phenomenon exists. The importance of the differential spreading lies in the creation of a greater initial surface area for promotion of evaporation and dissolution in the water column. At this time, it is not clear that high volatility, usually associated with high toxicity, also correlates with high spreading coefficients, hence further work in this area is clearly indicated. Some preliminary work at the University of Toronto[7] indicated that toluene does exhibit substantially faster differential spreading and will in fact spread faster than the bulk of the oil, thus facilitating evaporation.

The Fay-Hoult model for the spread of oil identifies three regimes of spreading--inertial, viscous, and surface tension--and develops rates of spreading for each of these three regimes. Initially, gravity is important due to the hydrostatic pressure of the thickness of the oil slick. The spreading in the initial stage is retarded primarily by inertia. In the second regime, gravity-induced spreading is retarded by viscosity (shear stress) at the oil-water interface. In the last regime, gravity effects are diminished with the decreasing slick thickness, and surface-tension forces drive the spread, retarded by the viscous forces.

The boundaries of each regime, or equivalently the times of transition from one regime to another, are identified by equating acting forces. Since the importance of a particular effect decreases while another increases slowly, the division into three sharply defined regimes is an approximation for the convenience of analysis. Thus, the calculated sharp divisions in the rate of spreading, as shown in Figure 5-1, are a consequence of the model and will not be observed physically.

Because of the differential spreading phenomenon and the effects of evaporation and dissolution, establishment of precise spreading coefficients is a difficult task and one must consider some form of average spreading coefficients (as well as viscosity, etc.) for computational purposes. Furthermore, at the leading edge of the oil slick, the oil and water quickly become mutually saturated resulting in changes of the interfacial tension.

The constants of proportionality in Fay's force balance equations were analyzed by Hoult and Suchon,[8] Lee,[9] and Fannelop and Waldman.[6] Fay's recommended values were adopted for this study. The spreading equations are shown in Table 5-1 for the three regimes along with the equations for transition times between the three regimes. Figure 5-1 shows slick radial dimensions as a function of time for 10,000- and 50,000-bbl oil spills.

FIGURE 5-1. SPILL RADII VERSUS TIME FOR 50,000-BARREL AND 10,000-BARREL CRUDE OIL SPILLS

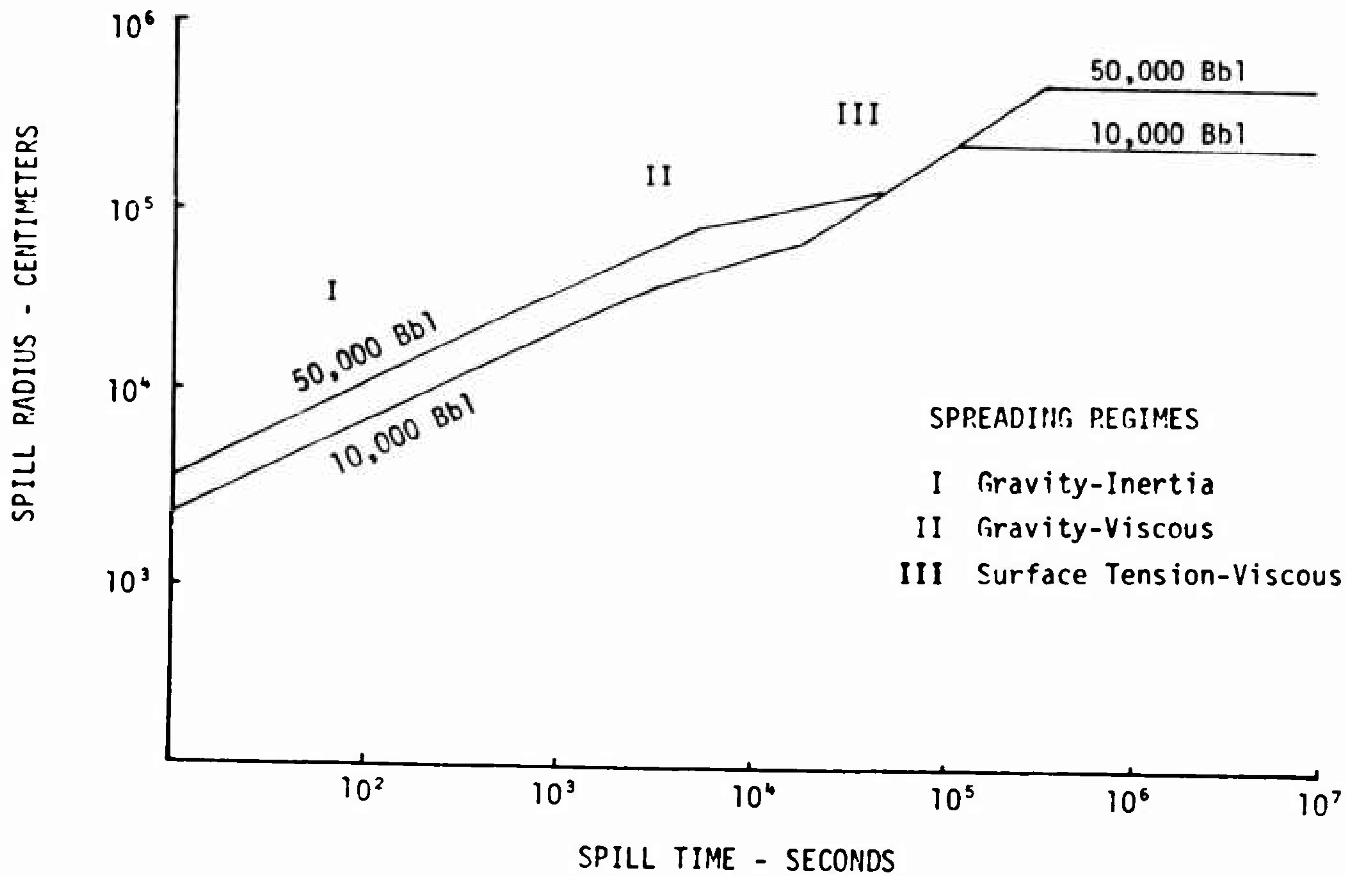


TABLE 5-1. SPREADING EQUATIONS FOR OIL SLICKS

I.	Gravity - Inertial	$r = 1.4\ (\Delta g V t^2)^{1/4}$
II.	Gravity - Viscous	$r = 1.45\ (\Delta g V^2 t^{3/2} / \nu^{1/2})^{1/6}$
III.	Surface Tension - Viscous	$r = 2.05\ (\sigma^2 t^3 / \rho^2 \nu)^{1/4}$

TRANSITION TIMES

Regime I $\longrightarrow$ Regime II	$\tau_{12} = 2.617\ (V/\nu \Delta g)^{1/3}$
Regime II $\longrightarrow$ Regime III	$\tau_{23} = 0.50\ (\rho/\sigma)(\nu \Delta g V^2)^{1/3}$

V = volume of oil spilled	(cm^3)
t = time from spill	(seconds)
ρ = density of water	($\sim$1.0 gram/cm^3)
$\Delta = (\rho - \rho_{oil})/\rho$	($\sim$ 0.1)
g = gravitational acceleration	(980 cm/sec^2)
ν = kinematic viscosity of water	($\sim$ 0.01 cm^2/sec)
σ = spreading coefficient	(10-40 dyne/cm)
τ_{12} = transition time from Regime I to II	(sec)
τ_{23} = transition time from Regime II to III	(sec)

In addition to the spreading equations developed for the three regimes, it has been observed that slicks spread to a finite size (or finite thickness) and stop, provided that no disturbances such as water turbulence or current and wind act on the slick. The maximum area to which the slick spreads is dependent on the initial oil volume. Fay[3] has reported an empirical dimensional formula for this maximum area, given as

$$A(m^2) = 10^5[V(m^3)]^{3/4} \tag{5-2}$$

where A is the final area in square meters and V is the volume of oil spilled in cubic meters. This formula is used by MSNW to calculate the limit of spreading.

Fay[3] postulated that the cessation of spreading is brought about by the diffusion of oil fractions into the water layer under the slick, increasing the water-oil interfacing tension. He then postulated the resulting equation for the maximum slick area as

$$A = k_a\left(\frac{\sigma^2 V^6}{\rho^2 \nu D^3 S^6}\right)^{1/8} \tag{5-3}$$

where

S is the solubility of the significant oil fractions

D is a diffusion coefficient

ρ is the density of water

ν is the kinematic viscosity of water

σ is the spreading coefficient or interfacial tension and

k_a is a constant of order unity

Equation 5-3 has the same value as Equation 5-2 for $S = 10^{-3}$, $D = 10^{-5}$ cm^2/sec, σ = 10 dyne/cm, and $k_a = 1$. There is uncertainty about the value of σ, but it is expected to be from 10 to 40 dyne/cm. For σ = 40 dyne/cm, k_a would have to equal 0.84 for Equation 5-3 to give the same results as Equation 5-2.

The equations developed by Fay do not include oceanic turbulence. Surface water turbulence was discussed by Waldman, et al.[10] They concluded that turbulence would tend to dominate in the latter stages of surface-tension spread. Dye-release experiments reviewed by Waldman, et al., led to an estimate of the slick radius given by

$$R \text{ (feet)} = 0.0114 \, t^{1.17} \qquad (5\text{-}4)$$

Waldman, et al., questioned the applicability of dye-release experiments to oil spreading because the dye mixes freely with the turbulent surface water, whereas oil does not. In addition, they pointed out that the loss of oil fractions with time alters the remainder of the slick to a tarry consistency. Thus, turbulence will tend to break up the slick into discrete blobs which will move relative to one another driven by dispersive forces.

If the spill occurs in Arctic waters, then the calculation of the maximum slick area will change because the surface tension phase of oil spreading is absent. As a consequence, the terminal size of the slick will be less. It is known from experimental observations[11] that spreading motion will cease when the oil reaches a thickness of the order of 1 cm; hence, the maximum slick area is calculated simply from area = volume/thickness.

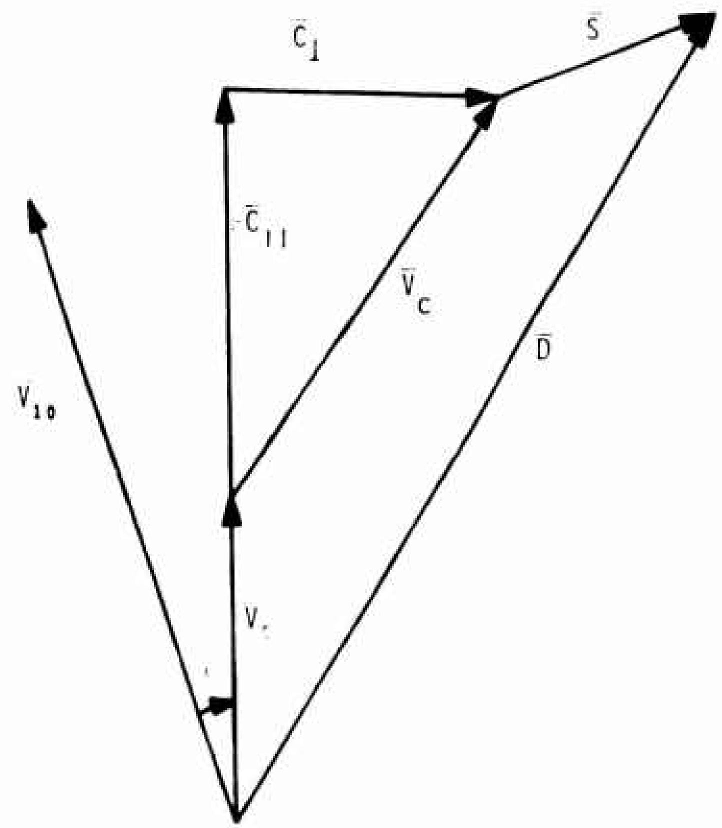
For a 50,000-bbl spill, this will give an area of 0.794 km^2, or a radius of roughly 0.5 km.

(2) OIL TRANSPORT OR DISPERSION ANALYSIS

The basic phenomena affecting movement of an oil slick are currents, winds, and waves.

Waves affect slick motion by direct transport and by wind shadowing. Direct transport is a combination of Stokes' transport and induced streaming. Stokes' transport is a phenomenon related to wave steepness and induced streaming results from the effect of a contaminated surface on increasing momentum loss of incoming short waves. Waldman, et al.[10] indicated that direct wave transport should be less than 20 percent of that due to wind and can, in most cases, be neglected. In part, this effect can be neglected due to the opposite effect of wind shadowing. Schwartzberg[12] found that wave shadowing reduced wind drift by almost 15 percent and, hence, concluded that the enhancement in slick drift caused by waves (Stokes' transport) might be compensated for by wind shadowing. In a recent report, Reisbig[13] explored the problem of wind-wave coupling in more detail and presented some experimental results. The principal conclusion was that at low wind speeds, the wave drift was shown to provide an augmentation to the wind drift, whereas at higher wind speeds, the waves caused a net decrease in the coupled drift velocity. The crossover between augmentation and wave-induced diminishment appeared to occur at approximately 80 cm/sec or 1.5-K wind speeds. Thus, neglecting the wind-wave coupling effects for higher wind speeds would be conservative for the purposes of estimating maximum impacted area for any particular spill.

FIGURE 5-2. OIL SLICK DRIFT SCHEMATIC



$\bar{V}_{10}$ - surface wind velocity vector

ι - drift angle

$\bar{V}_0$ - surface wind drift vector

$\beta\bar{C}_{||}$ - effective parallel current drift vector

$\bar{C}_\perp$ - perpendicular current drift vector

$\bar{V}_c$ - effective current drift vector

$\bar{S}$ - slick spread vector (normal to edge of slick)

$\bar{D}$ - resultant total drift vector

The effects of wind and surface currents are usually calculated to define a slick motion drift vector as follows (see Figure 5-2).

Starting with the wind vector $\overline{V}_{10}$, which is usually taken to be the surface wind velocity at 10 m above the surface at the point of interest, the direction of the surface wind drift vector $\overline{V}_0$ is established based on general atmosphere-water interaction principles (Eckman - Ref. 14 in James[15]) or local site studies. The drift angle can be related to wind duration and latitude by Eckman's results; James suggests that for mid-latitudes in the Northern Hemisphere, the drift angle is about 20 degrees to the right. The magnitude of the surface wind drift vector $\overline{V}_0$ is established by the use of the wind factor defined as

$$WF = V_0/V_{10} \qquad (5\text{-}5)$$

The values for the wind factor have been reported to range between 1 to 5 percent.[10,12,16-19] MSNW has elected to use a factor of 3.4 percent, which is the average of factors calculated from tracking segments of the "Torrey Canyon" spill.[10,12] The drift angle for the distances and for the latitudes of interest in this study was expected to be small and hence will be neglected. Furthermore, knowledge of surface wind data for the sites of interest to this study was incomplete in many cases so that wind had to be extrapolated from nearby measuring stations, resulting in considerable uncertainty in the wind data base.

Surface currents cause direct transport of an oil slick. The general approach to total transport of the slick has been to superimpose the contribution from currents and the surface wind drift vector. Laboratory experiments conducted by Schwartzberg[12] indicated that simple superposition may not be valid. Schwartzberg noted a reduction in total drift (wind and current) below that predicted by superposition, indicating coupling between current and wind effects. The reduction observed for winds parallel or antiparallel to the current amounted to 44 percent of the current drift. No experiments were conducted with the wind at an angle to the current due to the limitations of the experimental apparatus. Although some coupling from crosswinds affecting current drift is expected, with no evidence on which to base a judgment MSNW opted for direct superposition for currents perpendicular to the wind. For currents parallel to the wind, the reduction observed by Schwartzberg[12] has been adopted.

The resultant total transport equation is considered to be given by (see Figure 5-2):

$$\bar{D} = \bar{S} + 0.034\,\bar{V}_{10} + 0.56\,\bar{C}_{\parallel} + \bar{C}_{\perp} \tag{5-6}$$

where

- $\bar{C}_{\parallel}$ is the portion of surface current parallel to the wind
- $\bar{C}_{\perp}$ is the portion perpendicular to the wind
- $\bar{V}_{10}$ is the wind velocity vector
- $\bar{S}$ is the spreading velocity vector at the edge of the slick (taken as perpendicular to the boundary of the slick)
- $\bar{D}$ is the total resultant drift velocity vector

(3) MODELS FOR OIL SLICK MOTION PREDICTION

Models for oil movement on water can be generally categorized as spreading models, trajectory models, or transport models. Spreading refers to the thinning of the oil slick with time; trajectory refers to the movement of the center-of-mass of the slick, and transport refers to models which are concerned with the combined spreading and movement of the oil slick or portions of the slick.

Additionally, models must deal with leaks or instantaneous spills. The distinction between the two is that leaks refer to oil discharges which occur on a time scale comparable to the time of concern, and instantaneous spills refer to discharges which occur in a short time compared to the time of concern.

Differences between existing models vary from fundamental differences in the underlying transport and spreading equations to differences in handling data bases and presentation of output. Several models have been computer-coded and the coding is available in the literature.[20,21] Table 5-2 is a general categorization of the models encountered in the literature in the course of this study.

Several of the models offer unique features or interesting approaches to the modelling of oil movement on water. Murray, et al.,[22] did not take the standard spread and trajectory approach but applied two-dimensional dispersion theory analogous to the three-dimensional treatment of air pollutant dispersion in air quality analysis (e.g., Nawrocki, P.J., and R. Papa, [illegible], New Jersey: Prentice-Hall, Inc., 1963). After developing the dispersion equations applicable, they calculated appropriate values of the constants in the equations by comparing calculations to observed slicks at the Chevron spill site. This approach appears to have been motivated because the spill was a continuous leak. In addition, they calculated slick shapes due to the advection of continuously changing tidal currents.

Wang and Hwang[21] have included a feature in the Tetra-Tech model for oil movement in bays that indicates the calculated slick thickness on the printer plot output. The slick is displayed as a number representing a thickness of oil in 10^{-3} cm for the grid squares that the oil occupies. Successive printout enables one to follow the transport and thinning of the slick.

Stewart, et al.,[24] used a random wind approach to calculate a range of trajectories impacting on shoreline. They developed transition matrices for wind direction shifts based on data for 3-hour average winds at specific sites of interest. They analyzed the probable shore impact of an oil spill at one site using 200 computer runs, all of which started from the same spill origin point and used the same predominant wind. Wind directions were changed via a standard first-order Markov process. This process produces a new wind direction for each 3 hours of simulated spill history in line with observed wind shift data. The percentage of cases that slick trajectories impact each section of beach was then calculated. One disadvantage of this modelling approach is the necessity for making numerous calculation sequences in order to estimate beach impact probability. This disadvantage is somewhat offset by the fact that only a single point on the slick is monitored.

Other computer studies are listed in Table 5-2.

B. THE MSNW SPREADING AND DISPERSION MODEL

(1) GENERAL DESCRIPTION

The MSNW computer model incorporates the oil transport theories derived in the previous section and produces graphic outputs which clearly show the movement of the slick on a map or chart. The emphasis in develop-

TABLE 5-2. OIL ON WATER--TRANSPORT AND SPREADING MODELS

REFERENCE NO. AUTHORS, STUDY DATE (1)	MODEL TYPE[1] (2)	OIL RELEASE[2] (3)	TRANSPORT BASES[3] SPREAD[4] (4)	WIND[5] (5)	CURRENT[6] (6)	TOTAL[7] (7)	COMPUTERIZED[8] (8)
19. G. A. Waldman, et. al. 1973 AVCO Systems	Trajectory	Leak or Instantaneous	Calm Sea	Average	Average	Superposition	No
4. D. P. Hoult and J. A. Fay 1969 *OIL ON THE SEA*	Spread	Instantateous	Calm Sea	——	——	——	No
23. J. Vagners and P. Mar 1972 *OIL ON PUGET SOUND*	Transport	Instantaneous	Thickness	Time Variable Area Average	Time Variable Area Average	Superposition	Yes
20. R. D. Kaiser, et. al. 1974 EPA - Chesapeake Bay	Trajectory	Instantaneous	——	Time Variable Area Average	Time Variable Area Average	Superposition	Yes
22. S. P. Murray, et. al. 1970 Chevron Spill - Louisiana	Transport	Leak	Turbulent Dispersion	Time Variable Area Average	Time Variable Area Average	Superposition	No
21. S. Wang and L. Hwang 1970 Tetra Tech - Oil in Bays	Transport	Instantaneous	Calm Sea	Time Variable Area Average	Time Variable Area Average	Superposition	Yes
3. J. A. Fay 1971 Spread - API Study	Spread	Instantaneous	Calm Sea	——	——	——	No
24. R. J. Stewart, et al. 1974 MIT Report to CEQ	Trajectory	Instantaneous	------	Time Transitional Area Average	Time Variable Area Average	Superposition	Yes
25. C. R. Cole, et al. 1973 ARCO Study	Transport	Instantaneous	Calm Sea	Average	Time Variable Area Variable	Superposition	Yes
26. J. Premack and G. A. Brown 1973 Narragansett Bay	Transport	Instantaneous	Calm Sea	Time Variable Area Average	Time Variable Area Variable	Superposition	Yes
16. T. S. Murty and M. Khandekar 1973 Straight of Georgia	Trajectory	Instantaneous	--------	Average	Time Variable Area Variable	Superposition	Yes
-- Mathematical Sciences Northwest, Inc. Present Study	Transport	Instantaneous	Calm Sea	Time Variable Area Variable	Time Variable Area Variable	Coupled	Yes

Reference number refers to References List.

NOTES - TABLE 5-2

OIL ON WATER - TRANSPORT AND SPREADING MODEL

1. MODEL TYPE - This category relates the fundamental aim of each model.

   Spread - This type refers to any model primarily concerned with the dynamics of oil spreading on the water surface and the forces causing the spreading motion. Movement of the center-of-mass of the oil is generally ignored.

   Trajectory - This type refers to any model which is primarily concerned with the center-of-mass movement of the slick.

   Transport - This type refers to any model which is concerned with movements of portions of the oil slick due to the influences of wind, current, and spreading forces.

2. OIL RELEASE - This category refers to the time scale of oil discharge.

   Leak - Refers to situations where oil is continually released over a major portion of the time of concern.

   Instantaneous - Refers to situations where a quantity of oil is released in a period short compared to the time of concern.

3. TRANSPORT BASE - This category refers to the major forces which move and shape the oil slick; spreading, wind, and current forces.

4. SPREAD - This category refers to the spreading forces used in the model.

   Calm Sea - This type is characterized by the equations developed by James A. Fay (Refs. 3 and 4).

   Turbulent Dispersion - This type was developed by Murray, et al. (Ref. 2) analogous to two-dimensional dispersion of air pollutants. After deriving the dispersion equations for the Chevron Spill study, values of the constants in the equations were evaluated by comparison to observed slicks.

   Thickness - This type refers to the circular spread of an oil slick based on an equation for the thickness of the slick as a function of time, volume of oil, and oil specific gravity as developed by Battelle.*

---

*Battelle Memorial Institute, *STUDY OF EQUIPMENT AND METHODS FOR REMOVING OIL FROM HARBOR WATERS*, BMI Report #C12-70-001, August 1969.

NOTES - TABLE 5-2 (CONT'D.)

5. WIND - This category refers to wind force on the oil slick and the type of wind used. All models apply a factor to the wind speed in calculating the resultant drift velocity. The factor is generally recognized to be in the range of 3 to 5 percent.

   Average - Refers to use of the average wind velocity and direction over the time or area of calculation concern.

   Variable - Refers to the ability to program in various wind velocity and direction data for various times or areas.

   Transitional - Refers to the ability to let the wind direction (and velocity) change with time according to observed tendencies. For this, site historical data must be gathered and analyzed to yield the probabilities for changing from a given wind to another value.

   The above apply to both time and areal considerations, e.g., a model can allow time variation of wind, but this wind will represent an average value for the area of concern.

6. CURRENT - This category refers to current drift due to tidal currents, major oceanic eddies, shore outflow from rivers, etc.

   Average - Refers to use of average current value over time and area of concern.

   Variable - Refers to ability to modify current direction and velocity for different times and/or different areas.

7. TOTAL - This category indicates the treatment of the force components in calculating the resultant total drift.

   Superposition - Indicates those models which separately sum the effects of each force component.

   Coupled - Indicates those models in which wind and current interact, and the resultant drift is not simply the vectoral sum of the two.

8. COMPUTERIZED - This category indicates those studies in which the spill model has been put onto computer for handling calculations, etc.

ing this model has been to simplify input (including ease of geographic representation), provide for realistic representation of winds and currents, and provide easily interpreted graphic output. The intention was to develop a computational framework that would be compatible with future developments in oil transport theory.

The model represents the edge of the oil slick as a many-sided polygon. The number of points involved is variable and can change with time as the complexity of the slick geometry changes. The points on the slick edge are acted on (moved) by the forces of wind, current, and spreading as shown in Figure 5-2.

The various tidal current regimes, varying by location in magnitude and direction, are represented on the map by four-sided "Tidal" polygons. The magnitude of the current and the direction (ebb or flood) in each of these polygons is, in turn, also a function of time. The time variation of the tidal currents may be represented by a sinusoid or by actual tide curve data.

The model tests each point on the edge of the oil slick and determines which tidal polygon the point is in at the given time, computing the appropriate drift vector. The slick may encompass several tidal polygons at any given time, in which case the shape of the slick will be distorted from the circular shape caused by spreading forces alone. Distortion of slicks occurs in nature and is evident in several of the plots shown elsewhere in this report.

The effects of surface winds are handled in the same way as the tidal currents. It was found, however, that for the hypothetical spill cases around the coast of Alaska, there was insufficient data to warrant the development of "wind" polygons. In all cases, the wind was assumed to be constant in direction and magnitude for the duration of the simulation (72 hours maximum). As with the tidal polygons, the wind direction or magnitude may be varied as a function both of location and time. The shorelines are digitized from a map or nautical chart and are also represented internally as many-sided (over 2,000 in some cases) polygons.

The model "reads" the shoreline data, the tide and wind data, the spill location, and the oil type data, and computes movement of the slick boundary in discrete variable time steps. Parameters such as oil volume or density, spill location (for moving sources), or wind direction may be varied for each time segment. Any or all iterations (time steps) may be plotted.

The coordinates of the points describing the edge of the slick are saved after each iteration so that subsequent plots may be made showing alternative iterations, various scales, etc. In addition to the plotted output, the model produces a printed output displaying the amount of spread, the total slick area, the number of points describing the slick edge, and other pertinent information for each iteration.

Input may be supplied in several types of units (i.e., barrels, gallons, tons, etc.). Internal computation and output are in metric units.

The program is written in FORTRAN for the CDC 6000 series computers operating under the SCOPE 3.4 system. Geographic input was prepared using a Benson-Lehner digitizer and the plotted output was prepared using a CalComp plotter.

(2) THE POINT IN POLYGON CONCEPT

As may be inferred from the foregoing description, a large part of the computer work load is dedicated to tracking the edges of polygons and testing to determine whether or not a given point is in a particular polygon. For example, a point on the edge of the oil slick is tested to see if it is in a given tidal polygon in order to determine the tidal current vector.

Similarly, the same point may be tested to see if it is within the confines of a polygon defined by the shoreline; if so, the slick has beached. Conversely, a point in the shoreline polygon may be tested to see if it is within the oil slick polygon so that the point in question may be listed as impacted by the oil (Figure 5-3).

Fortunately, a great deal of work has been done in the field of polygon retrieval of geocoded information for use in urban data analysis. A set of very efficient algorithms was developed by Dr. Helaman Ferguson[27] for the Urban Data Center, University of Washington, three of which were used extensively in this model (see subroutines CAUCH, CART, and AREA).

Figure 5-4 illustrates the basic logic behind the subroutines. A point which is known to be outside the polygon in question is connected by a vector to the point to be tested. If this vector crosses the sides of the polygon an odd number of times, the point is in the polygon. If it crosses an even number of times, the point is outside the polygon.

(3) GRAPHIC INPUT AND OUTPUT

The shoreline data are generated by means of a digitizer. This device generates x and y coordinates, from some arbitrary origin, when a

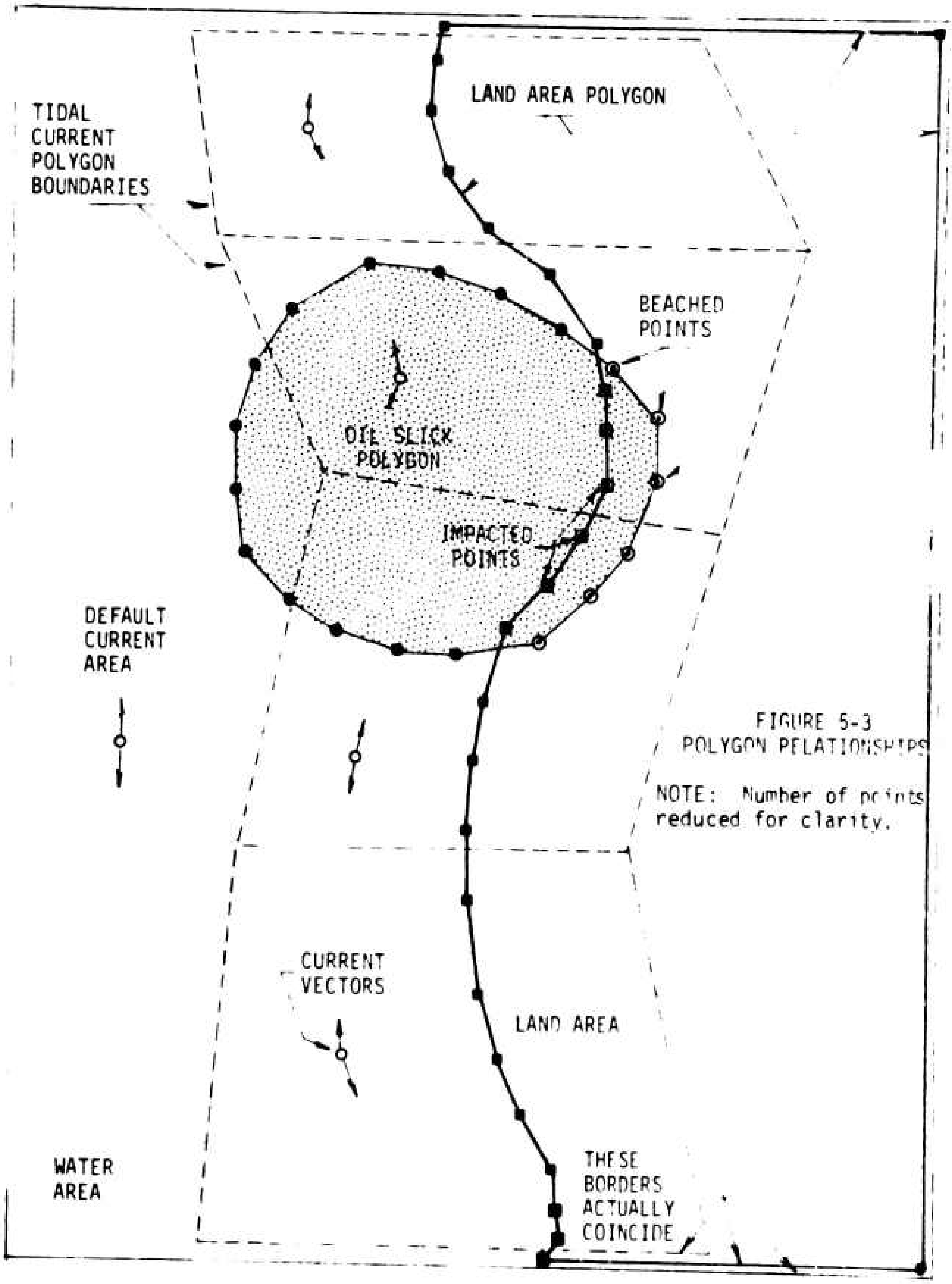
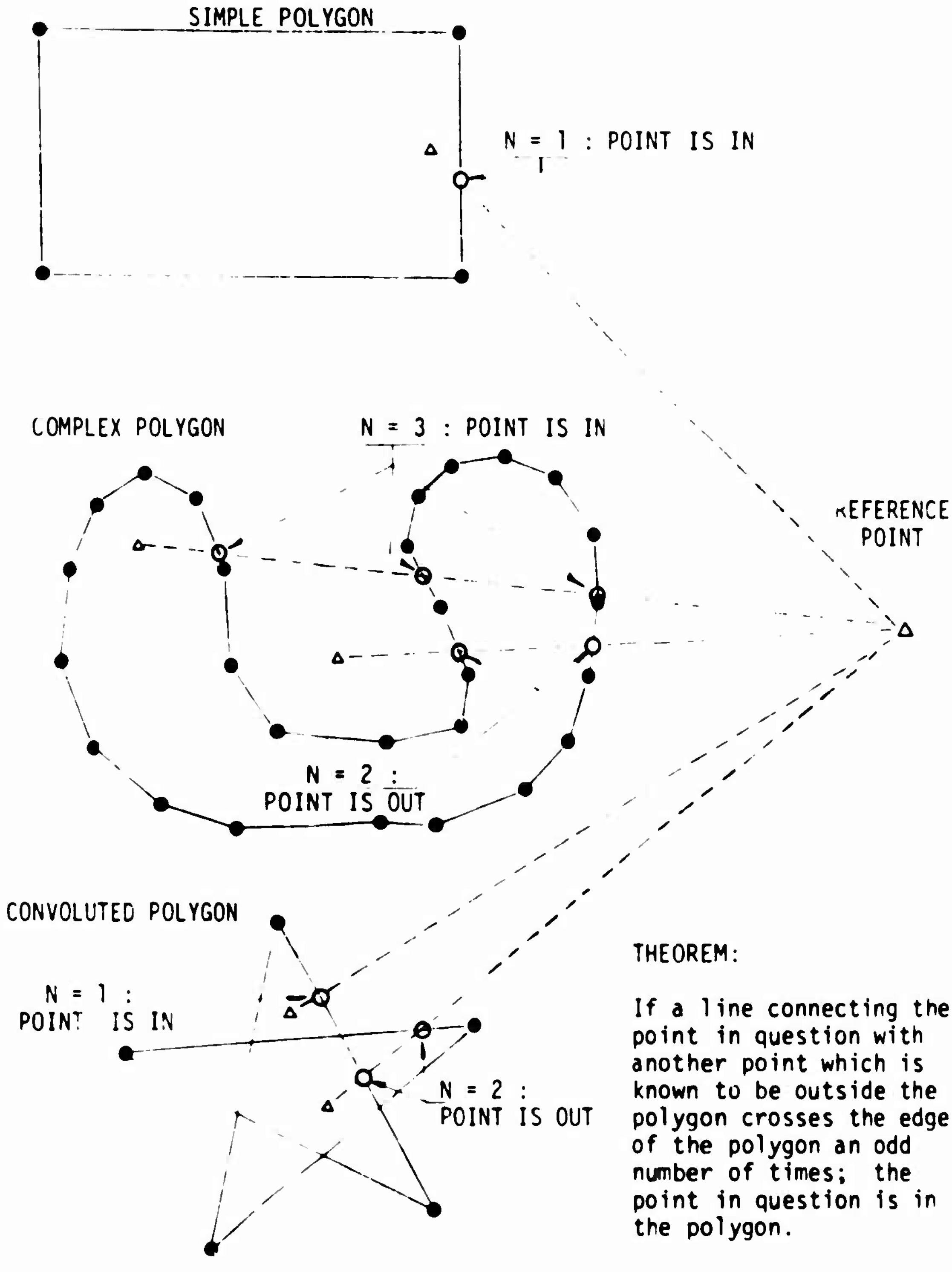


FIGURE 5-3
POLYGON RELATIONSHIPS

NOTE: Number of points reduced for clarity.



THEOREM:

If a line connecting the point in question with another point which is known to be outside the polygon crosses the edge of the polygon an odd number of times; the point in question is in the polygon.

FIGURE 5-4. POINT IN POLYGON TESTS

cursor is moved over the face of a map or chart. A digitizer may be thought of as having the reverse function of a plotter.

In addition to generating the x and y coordinates for any point on a map, the digitizer has a keyboard on which additional data may be entered and associated with the point. These data are then written directly onto a computer tape. Digitizing is a very rapid means of coding this type of data, each site taking less than one hour to encode.

Each shoreline point was coded as to physical type (i.e., rock, cobble-gravel, sand, mud). This allowed the computation of the amounts of shoreline by type at each site (Figure 5-5) and plots showing the shoreline types (Figure 5-6).

In addition, the 10-fathom (60 ft) depth contour was digitized and is presented as a dotted line on the plots. In some cases, the tidal polygons were also digitized.

All of the digitizing was done from U.S. Geological Survey Quad maps at a scale of 1:250,000. The scale (size) of the output is variable and can range from full-size overlays to the 8.5 x 11 plots seen in this report (Figure 5-7).

The graphic output from the model was produced on a CalComp 936 drum plotter which allows plots up to 34 in. in width. The plotter receives x and y coordinates from a computer tape and moves an ink pen to the requested location. The resolution of this machine is 2 mils (0.002 in.).

At the option of the user, the model will plot the geographic features with the tidal polygons overlayed on them (Figure 5-8). This provides a ready means for error detection.

****

YAKUTAT SHORELINE SUMMARY

****

	SAND	MUD	COBBLE	ROCK	TOTAL
LENGTH (IN METERS)	101962.07	95173.13	207578.59	138987.31	543701.10
PERCENT OF TOTAL	18.75	17.50	38.18	25.56	

FIGURE 5-5

SUMMARY OF SHORELINE BY TYPE COMPUTED FROM THE DIGITIZED MAP USED IN THE MODEL

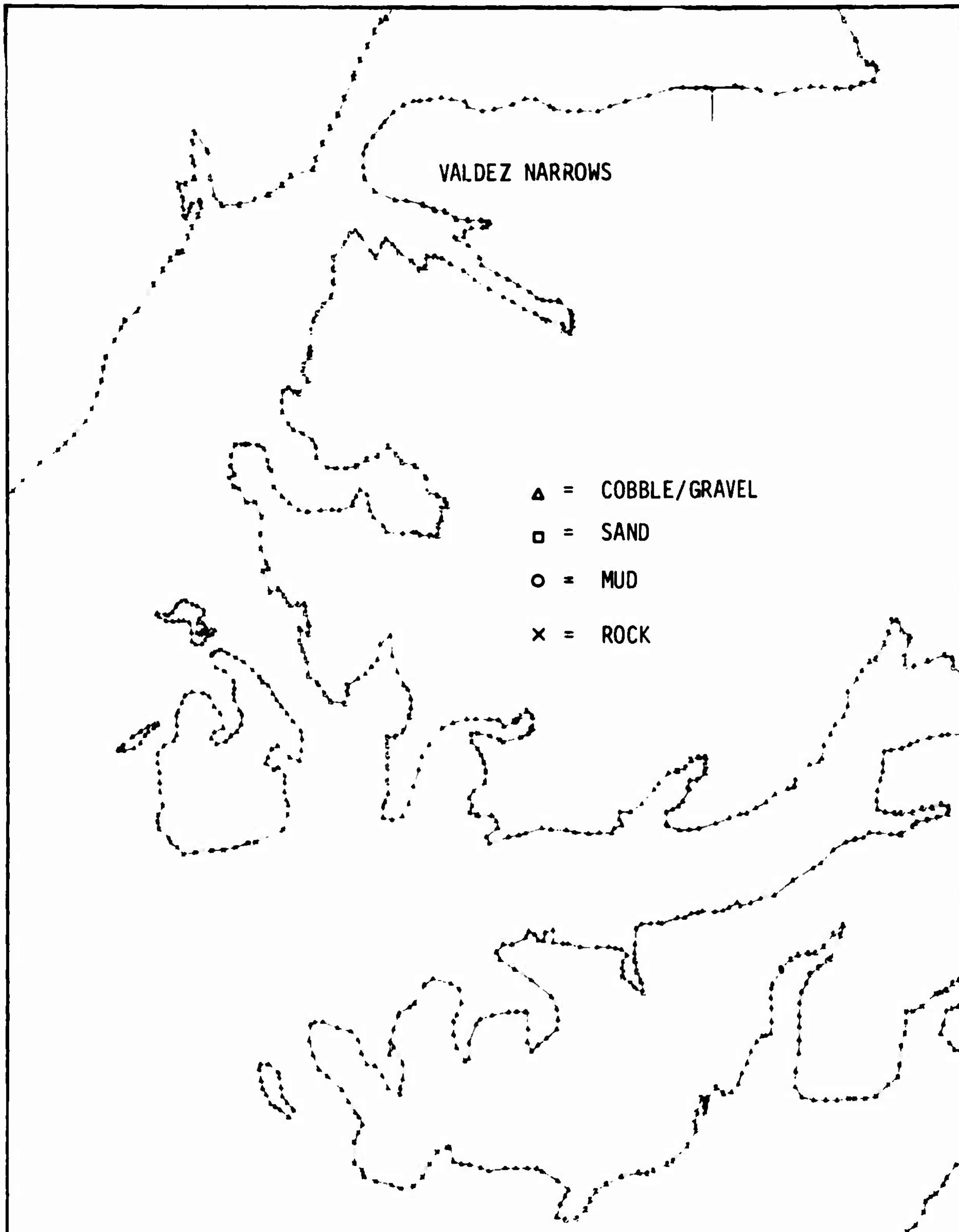


FIGURE 5-6. SHORELINE TYPE CODING

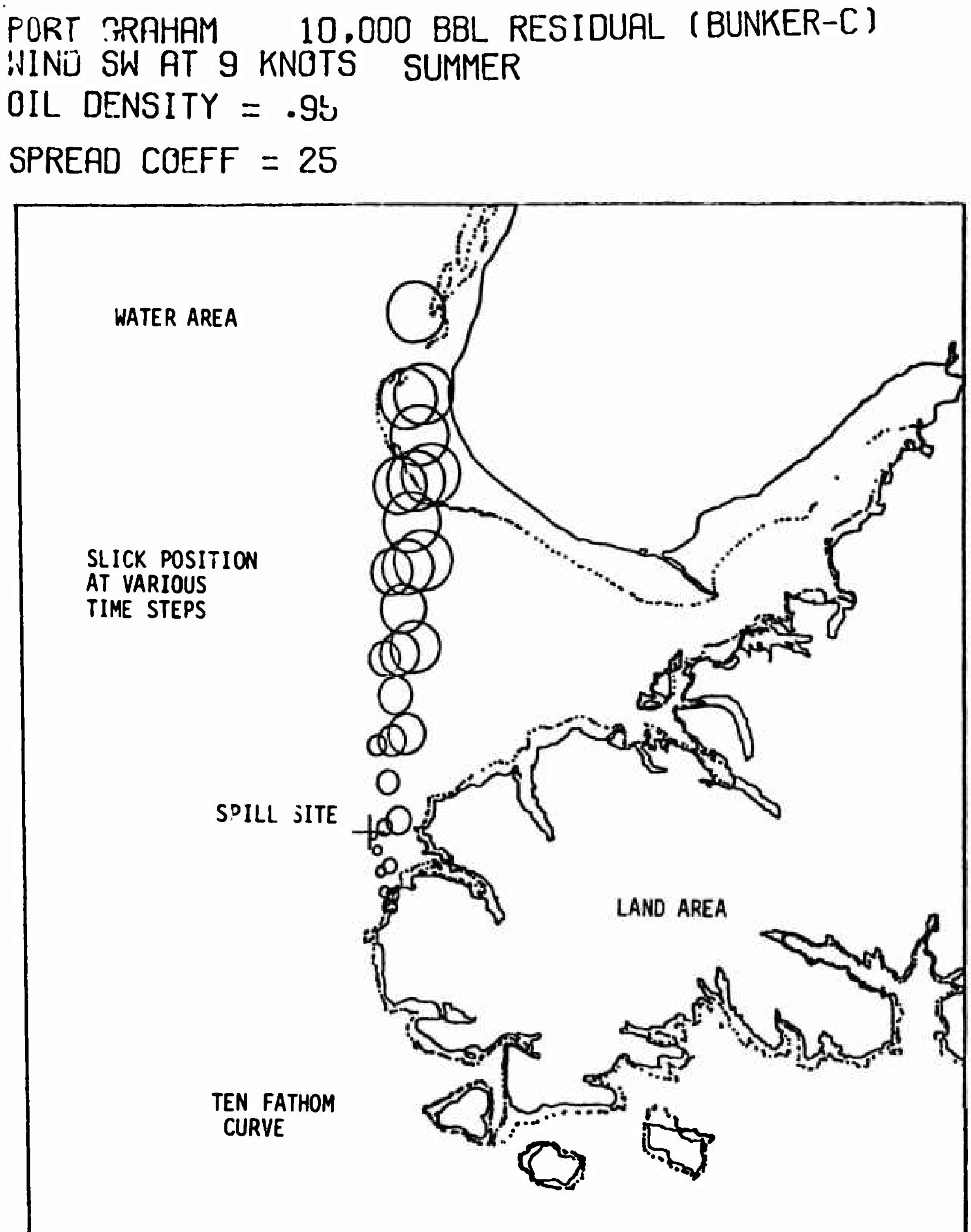


FIGURE 5-7. TYPICAL PLOTTED OUTPUT

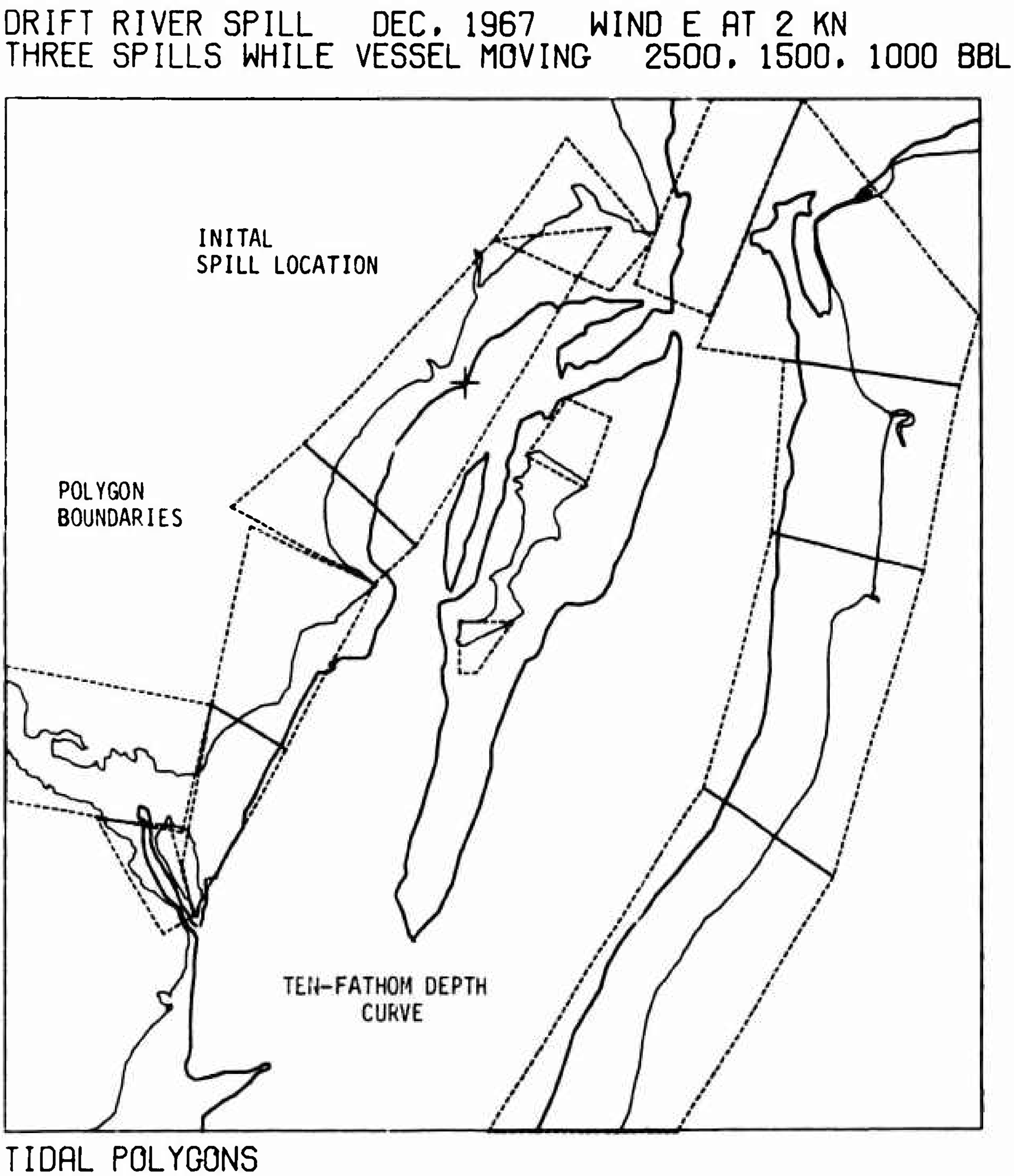


FIGURE 5-8. COMPUTER PLOT OF TIDAL POLYGONS

During a production run, the model plots the site map and the spill origin. The simulated time increments are variable (one-hour increments were used in nearly all cases) as is the choice of which increments will be plotted. For clarity, it was found best to plot only every third or sixth hour (i.e., at tidal extremes).

In any case, the coordinates of the points defining the slick edge are saved on an auxiliary disk file at the end of each iteration so that auxiliary plots may be made at a later time without having to repeat the computations. These auxiliary plots may be at a different scale and show different iterations than the original.

(4) MODEL ORGANIZATION

The model is organized as a main program with 11 subroutines as follows:

SLICK	-	The main program handles all input and output and controls slick behavior as described in detail below.
GEOPLOT	-	Reads the geographic data from the digitizer tape and plots the site geography.
SPREAD	-	Determines the spread regime and computes the magnitude of the spread vector.
TIDAL	-	Determines the tidal polygon affecting a given point on the slick edge, determines the condition of ebb or flood, and computes the tidal current vector.
VECTOR	-	Converts an angle into unit vectors.
DRIFT	-	Combines the effects of wind and tide and integrates over time to produce the resultant drift vector.

AREA	-	Computes the area of an N-sided polygon.
CART	-	Determines if a point is interior to a given rectangle.
CAUCH	-	Determines if a point is interior to an N-sided polygon.
INTER	-	Determines the intersection of two vectors.
QUAD	-	Determines the quadrant that a point is in.
AUXPLOT	-	Makes auxiliary plots of a given model run.

The main program is functionally organized as follows:

a. Read Headings

b. Read Program Control Card

   1. Size of time increment.
   2. Total time limit.
   3. Original map scale.
   4. Initial number of points to define slick.
   5. Size factor for output plots.

c. Read Physical Properties Card

   1. Coordinates of spill location.
   2. Volume of spill.
   3. Initial density of oil.
   4. Kinematic viscosity of water.
   5. Density of water.
   6. Interfacial tension (spreading coefficient).

d. Print Headings

e. Print Physical Properties

f. Read and Print Tidal Data

g. Read and Print Wind Data

h. Initialize Time Dependent Variables

i. Initialize Position Dependent Variables

j. Read Geographic Data File

k. Plot Site Geography

l. Compute Transition Times for the Spread Regimes

m. Compute Spread Magnitude

n. Compute Current Vector

o. Compute Wind Vector

p. Compute Drift Vector

q. Find Unit Vector Normal to the Slick Edge at Each Point

r. Compute Coordinates of New Location for Each Point

s. Test for and Eliminate Anomolies (i.e., Loops) in the Slick Edge.

t. Test for Shoreline Interaction.

u. Plot the New Slick Location.

v. Increment Time Dependent Variables

w. Stop if Time Limit is Reached

x. Return to Step m.

The major submodels are described in more detail in the following sections.

(5) TIDE SUBMODEL

Tidal current patterns in coastal waters can be very complex, and very little detailed data are available for the coast of Alaska. It is recognized that even the well detailed tidal current charts which are available for areas such as Puget Sound[28] cannot show all of the subtleties of back-eddies and tide rips.

For the most part, the tidal current data for this study were taken from the available tidal current tables[29] and the *COAST PILOT*[30], supplemented with some local knowledge. Since detailed information was scant, it was decided to establish a standard (default) tidal field with magnitude and direction for each site and then allow exceptions to this condition as knowledge and geometry dictated.

The range of the tidal currents (ebb and flood) may be predicted and categorized for general areas as diurnal, semi-diurnal, or mixed, depending on the number of tidal cycles per lunar day (24-3/4 hours). Most areas have either a semi-diurnal or mixed tidal cycle which can be fitted very closely by a sine wave of proper amplitude and period during some phases of its progression.

Since all of the spills in this study are hypothetical and not fixed as to a particular point in time, the simplifying assumption was made that for the relatively short time period of each simulation (less than 72 hours), a sine wave with a 6-hour period could be used to model the tidal cycle (Figure 5-9).

The further assumption was made that the spill would occur at slack before ebb on the opinion that a tanker would probably get under way on a favorable tide. The model was designed so that the starting time of the tidal cycle could be offset to any point in time.

For the open sea conditions (such as Offshore Prudhoe Bay) where there is no discernible ebb and flood, the tidal current submodel is modified so that the currents are a function of wind direction, taking into account the coriolis effect.

The default tidal field for each site was developed using data for the maximum flood and ebb so that the magnitude of the tidal current vector

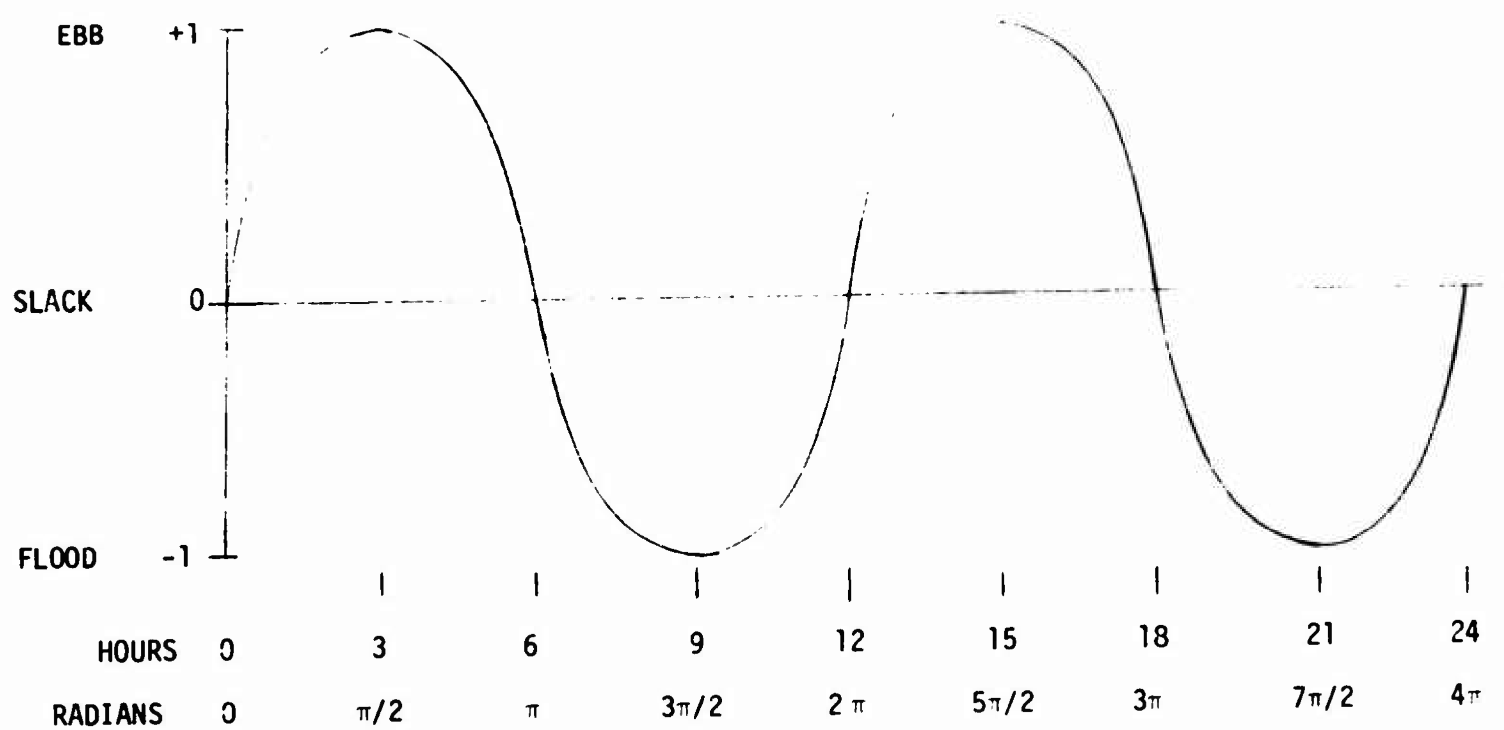


FIGURE 5-9. IDEALIZED TIDAL CURRENT CURVE

at any given time could be determined by multiplying the maximum current speed times the value of the sine function at the particular point in time.

The magnitudes of the tidal current exceptions were developed as a function of the speed of the default condition. Figure 5-10 shows the model listings of the tidal data for the Drift River site. The line marked DEFAULT gives the direction and magnitude of the mid-channel tidal current for both flood and ebb. The tidal polygons, each with a direction and a magnitude referenced to the default value by the factor shown, are listed below this line.

As an example of how the submodel works, assume that a point on the edge of the oil slick is found to be in the 5th tidal polygon, eight hours after the spill took place. Referring to Figure 5-9 and converting hours to radians, the value of the sine function is found to be:

$$\mathrm{SIN}\left[8 \text{ hours} \times \frac{\pi}{6} \ \frac{\text{Radians}}{\text{Hour}}\right] = -\ 0.866$$

The negative value indicates that the tide is flooding. The direction of the flood tide for the 5th polygon is 25° azimuth (from Figure 5-10). The magnitude of the current is computed by taking the magnitude of the default flood current (2.15 knots) times the factor for polygon 5 (1.767) times the absolute value of the sine function (0.866), or

$$(2.15)(1.767)(0.866) = 3.29 \text{ knots}$$

This value (in cm/sec) is then converted into a tidal current vector which contributes to the motion of the point as in Figure 5-2 .

MATHEMATICAL SCIENCES NORTHWEST
OIL SPILL SIMULATION MODEL

DRIFT RIVER 50,000 BBLS. NO. 2 DIESEL OIL
WIND NNE AT 0.0 KNOTS WINTER 2576.85

TIDAL POLYGON DATA

	FLOOD			EBB			COORDINATES IN MAP INCHES							
POLYGON	DEGREES	KNOTS	FACTOR	DEGREES	KNOTS	FACTOR	X1	Y1	X2	Y2	X3	Y3	X4	Y4
DEFAULT	20	$\boxed{2.15}$	1.000	200	2.55	1.000								
1	20	2.20	1.023	205	1.51	.594	7.90	0.00	11.40	5.40	13.50	4.00	11.00	0.00
2	20	3.00	1.395	205	2.30	.902	11.40	5.40	12.50	9.40	15.00	8.80	13.50	4.00
3	20	2.40	1.116	195	2.60	1.020	12.50	9.40	12.70	12.10	15.60	11.70	15.00	8.80
4	345	3.80	1.767	175	3.60	1.412	11.30	12.30	13.00	16.20	15.90	12.80	15.60	11.70
$\boxed{5}$	$\boxed{20}$	3.80	$\boxed{1.767}$	205	3.80	1.490	10.30	13.30	11.50	16.20	13.00	16.20	11.50	12.80
6	330	1.10	.512	180	1.90	.745	2.60	3.10	1.50	4.90	2.70	4.80	3.10	3.40
7	295	.55	.256	115	.95	.373	0.00	5.20	0.00	7.30	3.40	6.70	2.93	4.70
8	20	0.00	0.000	200	3.70	1.451	8.50	10.60	9.20	11.50	9.90	11.20	9.50	10.10
9	20	3.70	1.721	200	0.00	0.000	7.40	7.20	7.40	8.00	8.30	8.60	7.70	7.20
10	20	1.40	.651	180	2.20	.863	3.40	6.70	4.00	9.50	6.00	8.60	4.00	6.00
11	10	1.40	.651	150	2.20	.863	2.90	4.20	3.40	6.70	4.60	6.00	3.10	3.40
12	345	1.40	.651	130	2.20	.863	6.00	8.60	3.70	9.80	4.90	10.80	6.70	9.20
13	35	1.40	.651	215	2.20	.863	6.70	9.20	4.90	10.80	8.00	14.00	9.90	13.20
14	105	1.40	.651	165	2.20	.863	9.90	13.20	8.00	14.00	9.20	15.60	10.80	14.00

FIGURE 5-10. TIDAL POLYGON DATA LISTING

The model was refined to accept an actual tide curve in tabular form so that the effects of diurnal inequalities could be included. However, this feature was not used in this study.

(6) WIND SUBMODEL

"The wind goeth toward the South, and turneth about unto the North; it whirleth about continually, and the wind returneth again according to his circuits." (Ecclesiastes 1:6)

Little more than this is known about the topical details of surface wind patterns as they may affect an oil slick. This is especially true in the fjord-like bays in Alaska, due both to the complexities involved and to lack of observation.

Wind velocity (direction and magnitude) may be treated as a function of location and time as were the tidal currents described previously. Since the wind does not ebb and flood in a predictable way, the changes in velocity can be entered empirically or they may be treated statistically.[24]

While a wind subroutine analogous to the tide subroutine (TIDAL) may easily be inserted in this model, it was felt that the effort was not warranted owing to the lack of detailed wind information. All of the simulations in this report are for less than 72 hours and, in all cases, the wind velocity was held constant over this period of time.

(7) SPREAD SUBMODEL

The magnitude of the spread vector is computed by the subroutine SPREAD which uses the equations shown in Table 5-1. The direction of the spread vector is always outward, normal to the slick edge.

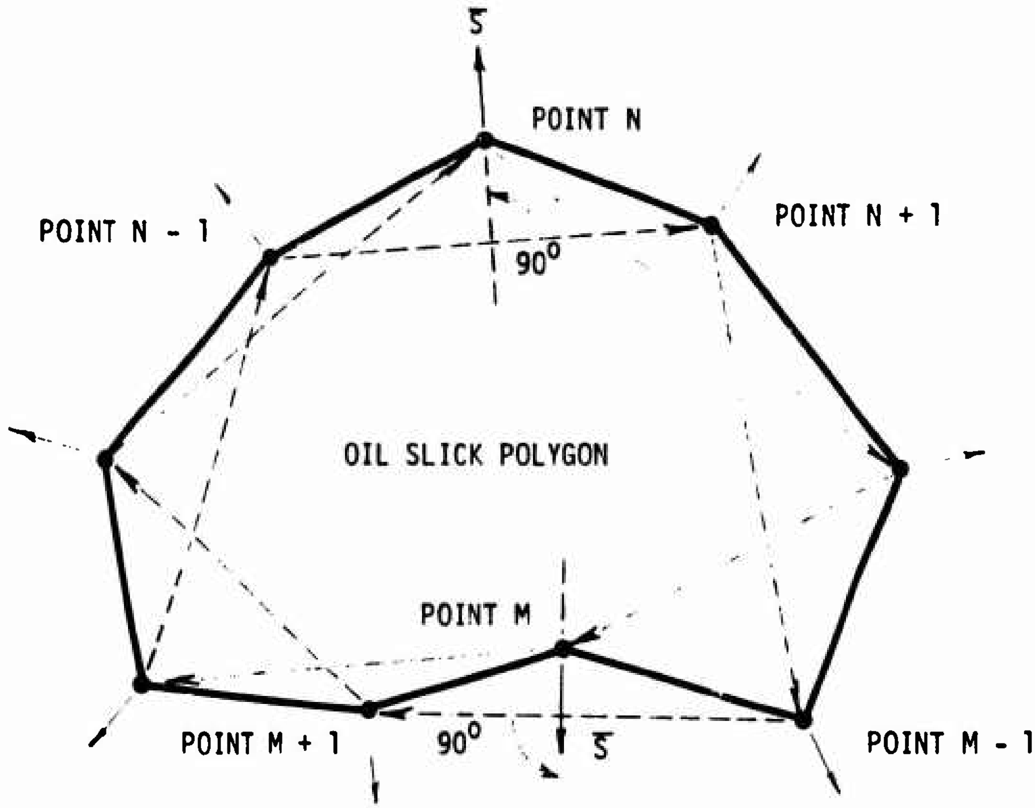
This vector was computed by connecting every other point on the slick edge with a vector in the clockwise direction and then rotating this vector 90^0 counterclockwise and applying it (reduced to a unit vector) to the point in between (see Figure 5-11). This unit vector, when multiplied by the spread magnitude, resulted in the proper spreading vector.

Under some circumstances, this method will result in a loop in the slick edge which must be eliminated before proceeding to the next time step. Occasionally, due to tidal action, the slick will assume a shape with a concave edge. If this concave angle becomes sharp ($\sim 90^0$), it is possible for two adjacent vectors to cross, resulting in a minute loop (Figure 5-12).

This loop, unfortunately, will continue to grow in successive iterations and is not representative of real slick action. Other loops (both interior and exterior to the slick polygon) may be formed if one side of the slick crosses another due to tidal action. This can occur, for example, if the leading edge of the slick enters an area of slow tidal current while the trailing edge is still in a faster current. A considerable amount of logic in the main program is expended to detect and correct this situation.

(8) DRIFT SUBMODEL

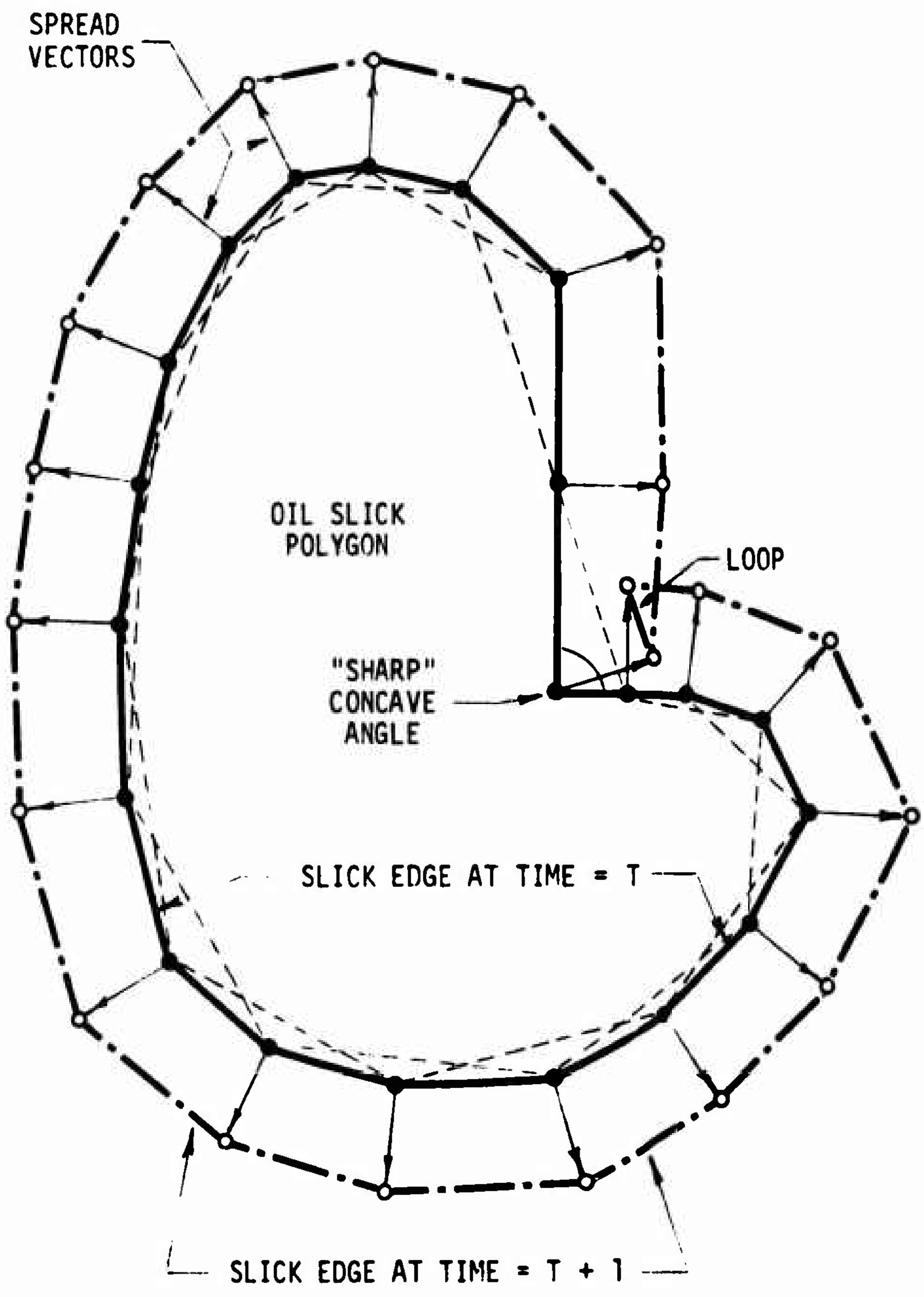
The drift subprogram takes the wind and current vectors, computes the current vector components parallel and perpendicular to the wind vector, and combines them as described in Figure 5-2. This subroutine also performs the necessary temporal integrations to produce a drift vector which may in turn be added to the spread vector to define the movement of each point on the slick edge.



METHOD:

Alternate points are connected by vectors in the clockwise direction. These vectors are then rotated 90^o in the counter-clockwise direction to determine the direction of a unit vector normal to the slick edge at the in-between point. The number of points on the slick edge have been greatly reduced here for clarity.

FIGURE 5-11. DETERMINATION OF SPREAD VECTOR DIRECTION



NUMBER OF POINTS IN SLICK EDGE REDUCED FOR CLARITY

FIGURE 5-12. PROPAGATION OF LOOPS IN THE SLICK EDGE

C. SPREADING AND DISPERSION OF OIL ON ICE AND LAND

Spreading of oil on a rough (solid) surface such as land or ice is governed by the following factors:

1. oil properties and composition
2. temperature of the oil and the supporting surface
3. wind velocity
4. the slope, roughness, and porosity of the solid surface

The principal determinants of the terminal oil pool of any given volume spill will be the viscosity (reflecting the influences of oil composition, temperature, and weathering effects) and the roughness and porosity characteristics of the supporting surface as well as its slope. From both experimental and theoretical considerations, it can be concluded that, in general, the terminal area of a given volume spill on land or ice will be orders of magnitute smaller than on water. For example, Hoult[31] calculated that a spill of Torrey Canyon magnitude (1.13×10^5 m^3) will be contained on 0.7 to 2.6 km^2 of ice in comparison with the estimated 780 km^2 of open water involved in the actual spill. Similarly, results from experiments on various snow, ice, and land surfaces by Mackay, et al.[7] indicated limited areal involvement.

The key factor then, in defining the impact of a spill on ice or land, is the extent to which the oil will be transported by various dispersion mechanisms, both short and long term. In the case of ice, one must consider the additional problem of spills under the ice surface and the subsequent time history of oil migrations vertically in the ice pack due to various mechanisms. Horizontal dispersion and transport mechanisms in the case of ice are defined by ice pack dynamics and general current circulation pattern. For land-based spills, transport mechanisms to be considered are meltwater runoff and possible avalanche or slide transport.

(1) SPREADING OF OIL ON AND UNDER ICE

When considering the spreading of oil on the ice surface, two aspects are of interest--the spreading rate and the terminal oil pool size. Both aspects have been investigated theoretically and experimentally and the principal features of the process are well understood. An excellent summary of the results to date is given by Hoult;[31] the main conclusions will be briefly reviewed here.

Experimental results from test spills conducted in the Arctic were reported by Glaeser and Vance,[11] Glaeser,[32] and McMinn.[33,34] A theory of spreading on a smooth surface was developed by McMinn[33,34] based on the assumption that only gravity and inertia forces are significant in determining the spreading rate. They derived the spill radius as a function of time as

$$r = 0.756\ (gQ)^{1/4}t^{3/4} \tag{5-7}$$

where g is gravitational acceleration, Q the average flow rate, and t time. This equation is compared to the experimental results in Figure 5-13 (taken from McMinn[33]); the data, however, are represented fairly well by the empirical relation

$$r = 1.3\ (Q^3g)^{0.1}t^{1/2} \tag{5-8}$$

Thus, it can be seen that agreement of theoretical spreading rate and experimentally determined spreading rate is poor. One can conclude, however, that

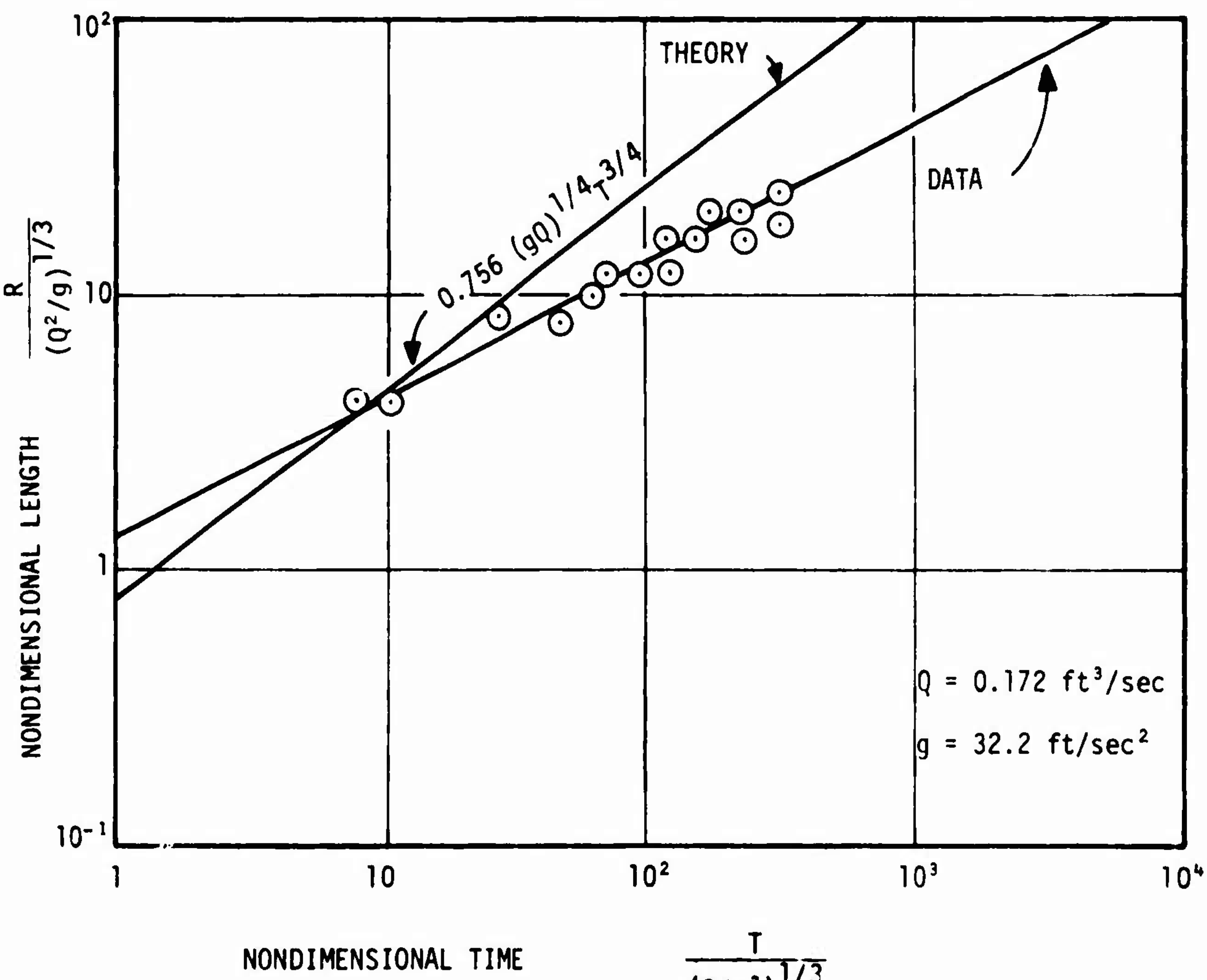


FIGURE 5-13. SPREADING RATE - WINTER ICE.

the assumption of only gravity and inertia forces acting is valid, since the data do not exhibit a break in the slope. These results are to be expected since the influences of the surface characteristics (roughness, porosity, etc.) have not been accounted for in the theory. From a practical standpoint, accurate knowledge of the spreading rate is not important since, in all likelihood, in any given spill incident the oil will have spread to terminal areas before any response action can be initiated.

The terminal oil pool area is determined primarily by the roughness characteristics of the supporting surface and, to some extent, by the porosity of the surface. Whereas all authors are in agreement on the fact that surface roughness, as defined by pocket size and distribution, is the principal determinant of pool size, some disagreement concerning the effects of porosity exists. Glaeser and Vance[11] reported that in spreading experiments (conducted during the Arctic Summer) of diesel and crude oils over a porous ice surface (consisting of a 2-in. thick layer of recrystallized ice), absorption by the surface layer of up to 25 percent of its volume in oil occurred. McMinn[33] reported (for Arctic Winter experiments) minimal (2mm) penetration when warm (56°) oil is poured on the snow surface (+5°F to -15°F). On the other hand, Mackay, et al.[2] and Ramseier[35] reported fairly extensive penetration. From analysis of the reported observations, one can conclude that the amount of penetration to be expected will depend on various physical parameters of the snow/ice surface, such as porosity, brine channels, crystal structure, etc., as well as the temperatures of oil and the snow/ice surface.

Assuming that limited absorption occurs, one can then use the theory of Hoult[31] to define the terminal pool size for any given volume spill.

The formula for the average area, $< S_{max} >$ covered by a spill of known volume V over (or under) ice is

$$< S_{max} > = \frac{4}{\pi^{3.2}} \left(\frac{V}{V_{mp}} \right) \Gamma^2 \tag{5-9}$$

where Γ is the horizontal length of the average ice pocket and V_{mp}, the average of the pocket, is given by

$$V_{mp} = \frac{2T^2}{\pi^2} (2\sigma_n)^{1/2} \tag{5-10}$$

where $\sigma_n^{1/2}$ is the roughness height. Hoult[31] gave the following estimates of $< S_{max} >$ for three sets of Γ and σ_n for a spill volume of 89,000 bbls (5×10^5 ft^3)

TABLE 5-3.
SPREAD AREA AS A FUNCTION OF ROUGHNESS AND LENGTH OF ICE POCKET

Γ	σ_n	$< S_{max} >$
115 ft	2.295 ft^2	7.20×10^5 ft^2
200 ft	1.016 ft^2	1.24×10^6 ft^2
540 ft	0.203 ft^2	2.78×10^6 ft^2

For a 50,000-bbl spill, using the values of Hoult, one finds the area to be between 4.04×10^5 ft^2 and 1.561×10^6 ft^2 (3.75×10^4 meters^2 and 1.45×10^5 meters^2). Assuming a roughly circular spill, these values correspond to spill radii of 109 m to 214 m. Thus, one may calculate the areal coverage of a given volume spill, but, for accuracy, one must have a good knowledge of the surface roughness distribution in the specific area of the spill. At the present time, extensive efforts are underway to characterize the statistical aspects of sea ice roughness using laser profilometers;

however, extraction of data for a specific location is extremely difficult. Since detailed knowledge of ice roughness characteristics at a specific spill site is not likely, one must crudely bound the likely impacted area and then verify actual areal coverage from inspection. For bounding purposes, one may assume a circular bounding radius of 0.5 km around the spill source, with reasonable expectation that the oil will be within this circle if no substantial ice pack deformation has taken place since the time of the spill. For long-term impact studies, one only needs to define the outer limits of any postulated spill and then attempt to trace the migration of the contaminated materials.

Finally, we note that contradictory evidence exists concerning the rate and extent of evaporation of oil under Arctic conditions and the implications on weathering. The data of McMinn[33] and Glaeser and Vance[11] indicate substantial aging under both Winter[33] and Summer[11] conditions, with slower aging under Winter conditions. The primary determinants of aging are wind, temperature, and presence or absence of snow cover. That these conclusions do not hold true for all possible spill situations is indicated by the observation of Ramseier, et al.,[36] who investigated an accidental spill of diesel and gasoline at Deception Bay, Hudson Strait. Ten days after the spill, they found substantial amounts of diesel oil; chromatographic analysis of clean diesel, all of which had been exposed several days in an open pool, showed only a loss of about 2 to 4 percent of the lightest fractions. It is hypothesized that the evaporation is governed by energy balance considerations in the air, oil, and ice or snow system. The vapor pressure of most components of diesel oil is of the same order of magnitude or less than that of ice and water at $0^{o}C$. If the temperature differentials are low, natural evaporation will be limited. Furthermore, as the oil is warmed by solar radiation, a temperature differential at the oil and ice/snow interface is established and heat transfer into the ice will take place. As long as the transfer of energy into the oil equals the loss of energy to the ice, very little evaporation of the oil will occur. At temperatures close to the melting point, the underlying ice will melt with little evaporation of the overlying oil.

The spread of an oil spill under a stationary ice field has been investigated by Hoult.[31] From both a statistical study and a laboratory simulation, it was found that the extent of an oil spill under a stationary field of pack ice would be limited to a small area compared with the size of the same spill in open water. From Hoult's[31] table, (reproduced on page 5-45 as Table 5-3), a 50,000-bbl spill would cover an area of about 10^{-1} km^2, using roughnesses characteristic of coastal ice (i.e., assumed to have roughness height about seven times greater than surface roughness. This estimate of sub-surface roughness is substantiated by the unpublished data gathered by the Applied Physics Laboratory, University of Washington, Seattle, Robert Francois, personal communication).

(2) TRANSPORT AND DISPERSION OF OIL IN ICE-INFESTED WATERS

From the above discussion, it is clear that to estimate the ultimate fate of oil in ice-infested waters and hence to assess the possible environmental impacts, a knowledge of (possible) transport and dispersion mechanisms is far more important than knowledge of the initial spreading mechanisms. The transport and dispersion mechanisms fall in three basic problem areas:

1. The interaction of an oil spill with the dynamic pack ice, by which we mean that the ice is both advected and being subjected to stresses from wind and currents, so that pressure ridges, rubble fields, and leads may form.
2. The small-scale absorption and entrapment of oil by sea ice.
3. The transport of suspended oil particles by general motions of water masses.

Extensive work on defining the dynamics of Arctic pack ice is currently under way within the AIDJEX program,[37] the results of which will be of use for fate of oil determination studies. The small-scale absorption and entrapment of oil by sea ice is presently under investigation by the Canadian Beaufort Sea Project.[38] In addition, work bearing on the ice dynamics question has been proposed under the Arctic Offshore Program and the Bering Sea Ice Dynamics project. What is known about each of the three categories of problems is summarized below.

(a) THE INTERACTION OF OIL SPILLS WITH THE DYNAMIC PACK ICE

Except in enclosed bays and protected shores, pack ice responds to wind and current stresses by moving and changing its shape. This ice motion and deformation will greatly complicate both any predictions of the areal extent of a spill and any cleanup.

Campbell and Martin,[39] Ayers, et al.,[40] and Martin and Campbell[41] suggested that the pack ice motion would interact with the spilled oil in several ways.

ADVECTION OF THE OILED ICE

Any oil entrained by the sea ice would be advected with the moving pack ice. For example, during a 1970 Summer oil spill study by the Coast

Guard off Point Barrow, Alaska, Glaeser and Vance[11] reported an eastward drift of their test floe. During the one-week period of the test, between July 23rd through 30th, the floe moved about 100 miles. Obviously, any predictions of the spread of an oil spill in moving coastal pack ice depends on an initial understanding and prediction of the pack ice motion alone.

Assuming that an oil spill occurs somewhere along the continental shelf of the Beaufort Sea, it is very probable that the oil would enter the Beaufort Sea Gyre, a cyclonic clockwise-circulation pattern of ice with drift speeds between 2.2 to 9.5 km per day, hence the circulation period is of the order of 7 to 10 years. Any oil on or under the ice pack will disperse in the pack through the growth mechanisms of sea ice; i.e., the upward flux of ice caused by alternate melting at the surface and freezing on the bottom. The freezing and thawing cycles would be affected by the presence of oil. Furthermore, oil which arrives at the surface of the ice may be transported horizontally on a melt layer of water to depressions in the ice (or open leads) where it will commence to sink into the ice as a result of radiation heating of the oil and consequent (accelerated) sub-oil melting of the ice. Even without alterations to the freeze-thaw cycle, oil under the surface can be expected to surface in four years, the equilibrium age of Arctic pack ice.

PUMPING OF OIL WITHIN THE LEADS

Campbell and Martin[39] stated that families of leads regularly open and close within the ice pack. If oil fills these leads, then the lead closure may pump the oil out of one set of leads into another set at a different orientation.

INCORPORATION OF OIL WITHIN PRESSURE RIDGES

A more important mechanism for the interaction of oil and leads is the capture and transport of oil by pressure ridges. When leads close, any newly formed ice within the lead is crushed together to form a pressure ridge. Parmerter and Coon[42] described this process as follows:

> As a lead closes, the ice growth within the lead is pushed both above and below the older surrounding pack ice. When either the excess weight of the ice above or buoyancy of the ice below exceeds the breaking moment of the older pack ice, the older ice breaks into rubble which is also pushed above or below the pack ice. The process continues to form pressure ridges which can reach heights of 5 m and depths of 40 m.

Obviously, any oil within the lead, whether or not it is incorporated within the new ice growth, will be bound up in the pressure ridge where it may or may not flow out into either the ice surface or under surface.

If, as Martin and Campbell[41] suggested, the oil remains bound up in the pressure ridge, then it will be nearly inaccessible for cleanup. Also, as the keel and ridge ablate, the oil will be slowly released into both the sea water and onto the surface. If the pressure ridge is also advected with a moving ice field, the ridge could serve as an oil source over a large area for a period of several years. More research in this area is urgently needed.

(b) TRANSPORT OF OIL BY CURRENTS

In two recent Arctic oil spills, small oil particles with a typical diameter of 10 microns have been observed to a depth of 50 m. For the Chedabucto Bay spill of bunker C oil, Forrester[43] estimated that 1 percent of the oil spilled was mixed into the water column; for the Deception Bay spill of Arctic diesel, Ramseier, et al.,[36] estimated that 10 percent of the spilled oil was mixed into the water. Bell's[44] observations of a deliberate spill at Resolute Bay, N.W.T., showed that when Norman Wells crude oil is released beneath the ice surface from a hose, the surface tension breaks the oil plume into many small droplets. Such droplets will very likely form in any well blowout or underwater pipeline break, and their subsequent transport by currents may be a major spreading mechanism.

On a large scale, MSNW noted that any oil particles entrapped in the water column (either during a Summer or Winter spill) in the eastern Bering Sea or major eastern Bering Sea sounds, would migrate to the Chukchi Sea and eventually to the Beaufort Sea gyre. It is well established (Coachman, et al.,[45] and Mountain[46]) that the ultimate destination of Alaska coastal Bering Sea water is in the Beaufort Sea. If the spill occurs during periods of ice formation or at a time the Bering ice pack is well-developed, the situation is somewhat different. Recent studies during the joint U.S.-USSR Bering Sea experiment (BESEX) (results of the U.S. contribution to the joint U.S.-USSR Bering Sea Experiment. Report X-910-74-141 May 1974, revised June 1974, Goddard Space Flight Center, Greenbelt, Md.) of ice and ice pack movement in the Bering Sea indicated that the (loose, very mobile) pack moves with the predominant wind at 3 percent of wind velocity and generally exhibits the 20 to 40 degree Coriolis deviation to the right of the wind vector. Since the dominant winds in the Bering Sea area during the Winter tend to move the pack in a southerly direction, one would expect the oil to migrate toward the pack edge and there it may become entrapped in the water column or be dispersed laterally along the pack edge. The pack edge dynamics are very complex and not clearly understood at this time.

(c) TRANSPORT OF OIL BY WIND

In areas where there are possibilities of strong winds over the ice pack, or shore-fast ice, oil droplets may be distributed over a large surface area. Observations at Deception Bay[36] indicated that wind-transported oil droplets would form small melt potholes of a few centimeters in diameter scattered over the ice surface due to preferential melting of ice under the deposited oil droplets. This mechanism must also be considered when estimating the total surface area potentially impacted by oil on the ice pack.

(d) SMALL-SCALE ABSORPTION OF OIL BY SEA ICE

The experiments on the direct entrainment of oil by sea ice divide into at least two categories:

1. Entrainment by first-year growing sea ice.
2. Entrainment by first-year melting sea ice.

Presently there is no information on oil entrainment by multi-year ice. Further, there is more experimental evidence concerning Part 1 above than Part 2.

ENTRAINMENT BY FIRST-YEAR GROWING SEA ICE

There are two laboratory and field studies related to the entrainment of oil by first-year ice. In the laboratory, Wolfe and Hoult[47] (summarized by Hoult[31]) studied the entrainment of 2-cm layer of oil injected under about 15 cm of ice. From their results, they showed that the ice trapped the oil in the following ways:

1. A sheet of ice grew beneath the oil layer, thus trapping the oil inside of the ice.

2. About 1 percent of the oil flowed up into skeletal layer, or bottom 1 to 2 cm, of the ice above the oil layer.

3. A still smaller fraction of the oil flowed up into the bottom 5 cm of the ice through what are probably brine channels (which Wolfe and Hoult called "air pockets").

Wolfe and Hoult also reported that the oil tended to "stick" to the sea ice; they are thus far the only observers to report this sticking. Finally, they showed that because the thermal conductivity of oil is about 1/16 that of sea ice, the oil layer serves as an insulating layer which is sandwiched between the sea ice and the sea water. The effect of this insulating layer is to reduce the ice growth beneath the oil layer.

In the field, R.F. Brown[48] is presently performing a series of 40-bbl controlled oil spill experiments at Cape Parry, N.W.T., for the Beaufort Sea Project. The spills are conducted inside of circular booms with a 30-m diameter in which 40 barrels give an average slick thickness of 1 cm. The ice within the booms is instrumented with thermistor chains, and the oil release is observed with an underwater television camera. Before release, the oil is heated to the water temperature.

As of this writing, Brown has completed five spills--using both Norman Wells crude oil with a pour point of -70^{o}C and Swan Hills crude oil with a pour point of -10^{o}C. The spills thus far consist of one open-water spill with Norman Wells crude; three spills with Norman Wells crude under ice of approximate thickness of 40, 50, and 60 cm, and a Swan Hills crude oil spill under 60 cm of ice. At the present time, at least three more spills are planned; one at the end of January, one on May 1st, and one during the ice breakup.

PROPERTIES OF THE OIL

In the open-water spill, ice grew under the oil and snow infiltrated the oil from above; with the oil-snow mixture formed a dirt-like substance similar to that reported by McMinn and Getman,[49] which could be cleared away with shovels.

The underwater spills were released from a hose under the ice. Using the camera system, Brown observed the oil to collect in pools under the ice. apparently caused by the small-scale undulations in the bottom surface so that the areal coverage of the spill was 50 to 75 percent of the area enclosed by the boom. Outside of the large pools of oil, Brown observed small droplets or thin lines of oil with a scale of order 1 to 10 cm. The particle shape varied greatly with the different spills.

For the Norman Wells spill under 50 cm of ice, where the oil was released from a pipe at a depth of 1.7 m below the ice-water interface, the oil outside of the pools formed irregularly shaped droplets. For the Norman Wells spill under 60 cm of ice, which was released from 5-m depth, the oil away from the pools formed into a lacework which consisted of thin lines of oil connected together at different angles. Finally, for the Swan Hills spill under 60 cm of ice, globular particles formed away from the pools, where the particle size decreased from a 2-cm diameter next to the pools to the 1-mm resolution limit of the television camera as distance from the pools increased.

For the first three spills, Brown also reported on the weathering, thermal behavior, and physical behavior of the spills. First, results from a gas chromatograph analysis showed a statistically significant weathering of the higher fractions of the Norman Wells spill on the open water; however, the oil in the underwater pools showed no significant weathering after 48 days.

Second, the coring observations from the spill under 40 cm of ice showed that the first 5 cm of ice above the oil spill were 5 percent oil; for this spill, about 2 mm of oil were absorbed per-unit-area. These cores also showed some flow of oil up into the brine channels to a height of 15 cm above the oil interface. Except for the oil entrained within the ice and a slight coating on the outside from the coring, no oil was observed to "stick" to the ice, thus contradicting Hoult's[31] observations. Below the oil layer, the ice grew in a curious 1-cm-thick freshwater cap before resuming its normal sea ice appearance. At this time, no explanation of this phenomenon is available, since the freshwater ice cap (or at least very low salinity ice exhibiting crystal growth structure characteristic of fresh water) was observed in a few isolated cores.

The thermistor chains showed that the temperature gradient across the oil layer was about 14 times the gradient in the ice; a fact consistent with the observation that the oil conductivity is about 1/16 that of sea ice. This oil layer was also observed to reduce the total heat flux through the ice.

Finally, the effect of the new ice growth beneath the oil pool was to squeeze the oil layer and thereby increase its internal pressure so that when, in one case, a SIPRE core hole was drilled into the layer, oil gushed up around the corer to a height of 40 cm. Thus, the pressure buildup in the trapped oil may either cause or contribute to rupturing of the ice which contains it.

ENTRAINMENT BY FIRST-YEAR MELTING SEA ICE

W. L. Bell[44] carried out a small-scale "oil-under ice" experiment in connection with the ARCTIC IV project at Resolute Bay, N.W.T., during May 1974. Specifically, Bell did a qualitative photographic study of the spread of approximately 60 gallons of Norman Wells crude oil spilled under 180 cm of ice on April 25, 1974. The oil was pumped under the ice using a gasoline handpump and observed by divers equipped with rebreather units.

His photographs show that immediately after leaving the release hose, the oil broke into small droplets which then spread under the ice, collecting into two big pools of approximate diameter 5 m and average thickness 2 cm, and numerous small drops. The drop size ranged from 10 to 1,000 microns, and the small bubbles under the ice were as big as 2 to 3 cm across and 5 to 10 mm thick. Bell observed the small droplets under the ice to move with the very weak tidal current. Approximately 10 cm of new ice growth occurred under the oil layer before the ice began to melt.

On May 28th, 32 days after the spill, Bell observed oil spots on the ice surface which had been shoveled clear of snow. His photographs suggest that the spots had a separation of 10 to 20 cm on a grid-like spacing. Within one day, these spots produced small melt ponds of water. Cores taken through the ice showed that the oil had moved up to the surface in the brine channels; further, the cores contained a large unmeasured amount of oil. To a height of 10 cm above the spill interface, the cores were totally saturated; above this height, the oil filled the brine channels.

There also was some evidence of crystal platelet growth through the oil layer, both from direct observations at the bottom of the cores and in that the flow of oil up any single-core hole was slight. Under the ice, there was direct evidence of brine flow through the oil layer--in the form of two ice stalactites growing beneath the new ice growth. The brine flow through the oil layer may have provided the water for the crystal growth in the oil.

Finally, gas chromatographs of the trapped oil showed no significant weathering over the 32 days; however, biological samples placed in cages about 3 ft below the spill hose were all killed, apparently by the dissolved aromatics in the sea water.

(3) SPREADING, DISPERSION, AND TRANSPORT OF OIL ON LAND

Although there have undoubtedly been numerous accidental spills on Arctic terrain in association with the exploratory drilling activity on the North Slope, very little quantified information is available in the literature. The only systematic study at the present time appears to be that of Mackay, et al.,[7] under the sponsorship of the Canadian Arctic Land Use Research Program. Some information may be gained from study of the accidental spill at Deception Bay reported by Ramseier, et al.[36]

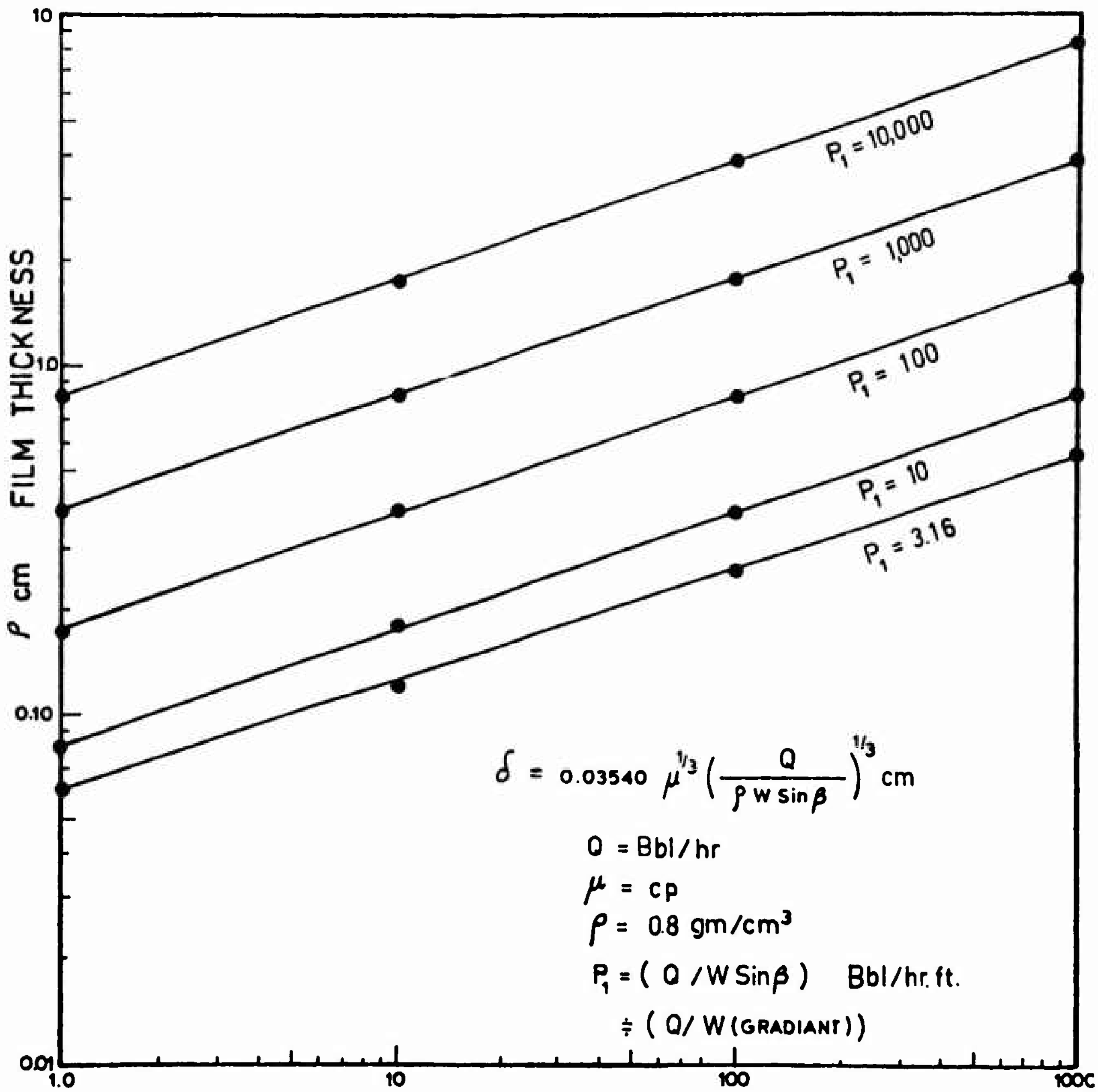
In considering flow of oil onto land, it is convenient to consider three basic situations:

1. Oil spilled under Summer conditions when the ground is free of ice and/or snow cover, and the spill does not enter a flowing stream or river.
2. Oil spilled under Winter conditions with snow and ice.
3. Oil spilled under Summer conditions, and the spill enters a flowing water system.

Under Summer conditions, the ground will usually be wet with surface runoff water. Oil will contaminate ground vegetation directly and will be absorbed by the ground cover. The flow characteristics will depend primarily on viscosity and the slope of the land. Mackay, et al.[7] developed simple expressions to estimate the oil film thickness as a function of viscosity, flow rate and slope for uniform, steady-state flow on inclined surfaces. Their charts (Figures 5-14 and 5-15) may be used to calculate approximate contaminated areas. For example, the area contaminated by a 50,000-bbl spill in 1 hour can be estimated to contaminate an area of 3.34×10^5 m^2 for a flow width of about 61 m. The charts of Figures 5-14 and 5-15 can be used for many different postulated terrain conditions to gain some feeling for the potentially contaminated area; however, because of the simplifying assumptions involved in generating the charts, the results should be used as a guide only. Channelization, nature of the ground (its absorption capacity, roughness, etc.), and presence or absence of flowing water, all can drastically influence the actual flow of the oil and should be considered from detailed topological information at the time of a specific spill. No general theory will adequately account for all the possible variables; however, simple calculations will yield the gross features of any specific spill.

The experimental data of Mackay, et al.,[7] does show the importance of considering subsurface contamination not revealed by visible oil in areas where moss or dense surface vegetation exists. Physical probing in areas dictated by the topography should be used to define the contaminated area which will be considerably larger than indicated by surface oil.

The effects of oil spills on the integrity of the underlying permafrost are not known at this time and clearly warrant careful, long-term study.



VISCOSITY μ (cp)

FIGURE 5-14. OIL FILM THICKNESS AS A FUNCTION OF VISCOSITY FLOWRATE AND SLOPE

SOURCE: Mackay, D., M.E. Charles, and C. R. Phillips, *THE PHYSICAL ASPECTS OF CRUDE OIL SPILLS ON NORTHERN TERRAIN*, Northern Pipelines Task Force On Northern Oil Development, Report No. 73-42, January 1974.

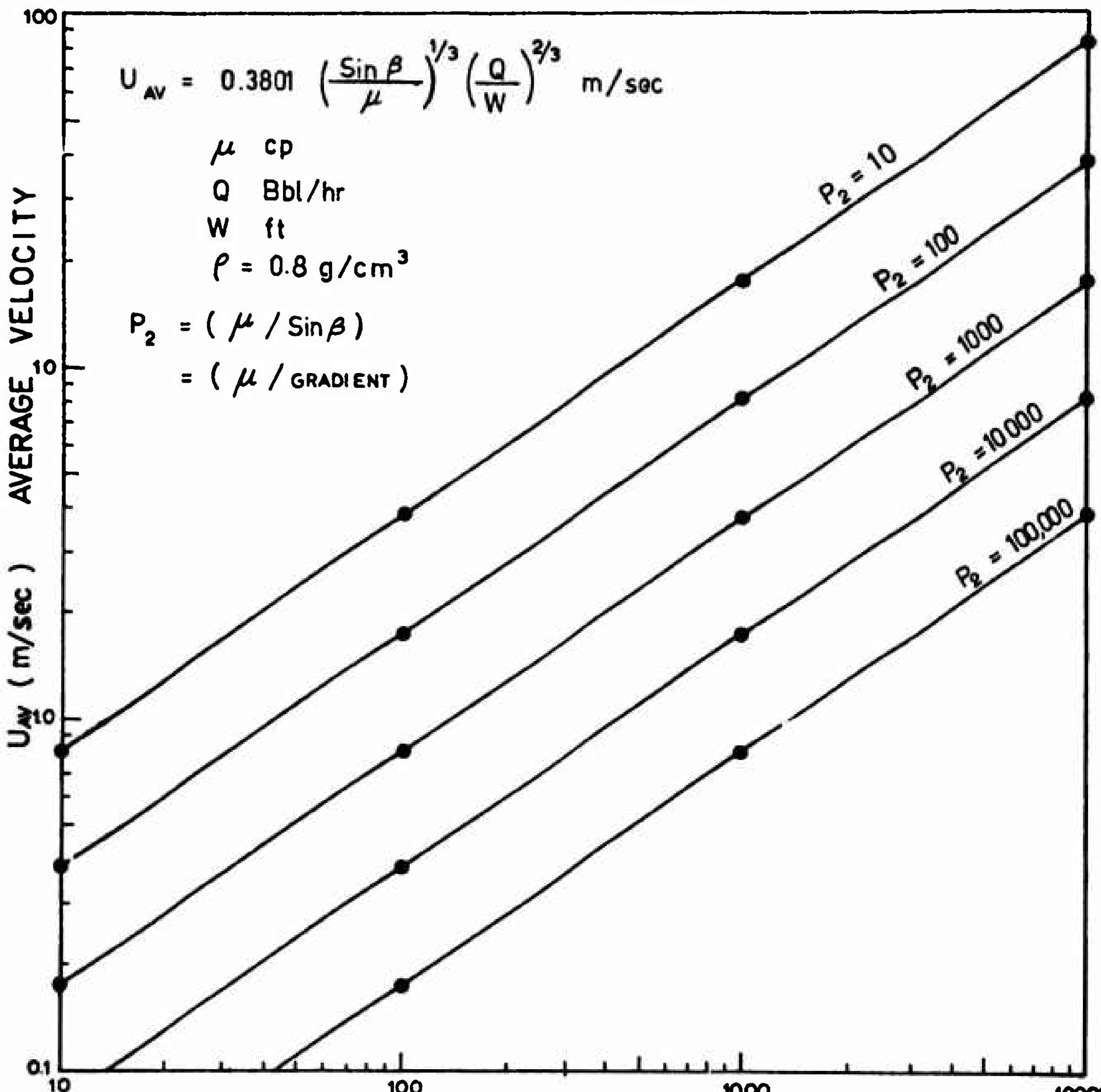


FIGURE 5-15. OIL FILM VELOCITY AS A FUNCTION OF VISCOSITY FLOWRATE AND SLOPE

SOURCE: Mackay, D., M. E. Charles, and C. R. Phillips, *THE PHYSICAL ASPECT OF CRUDE OIL SPILLS ON NORTHERN TERRAIN*, Northern Pipelines Task Force On Northern Oil Development, Report No. 73-42, Janauary 1974.

No significant changes in albedo are to be expected in Summer spills, hence no changes in absorbed radiation energy should occur. Formation of overlying pools does affect the drying out of the supporting surface.

If the oil spill occurs during Spring thaw or periods of heavy water runoff, one must consider the migration of the oil with the water. Any oil entering flowing streams or rivers will be carried a considerable distance from the original spill site and impact large areas. The extent and nature of downstream contamination will be determined by the river flow rate and turbulence. Turbulence will, in general, promote formation of oil-in-water or water-in-oil emulsions which are considerably more stable than the oil itself with regard to dispersion. The flowing water will deposit oil and oil-contaminated debris in the natural settling areas for the given river such as log jams, shallow bars, and settling pools below rapids. Bordering delta areas such as marshes, etc., will receive contamination; the fate of the oil in such environments is discussed in Part E.

Several new factors must be considered for a Winter spill. The behavior of oil, hot or cold, when spilled on ice or snow has already been discussed to some extent in Part C-1 above. In addition, for land-based spills, the influence of the slope must be considered in defining the contaminated areas. Oil may flow under a snow and/or ice cover for considerable distances with intact snow/ice bridges, or, if the oil stream is sufficiently wide, these bridges will collapse on the oil-- forming snow-oil emulsions (mulch). The extent of oil penetration into frozen ground is considerably less than for thawed ground.

Additional transport with attendant mixing may occur as a result of slides. As indicated by the accident at Deception Bay,[36] consideration of avalanche theory would indicate (see Figure 5-16 taken from Ref. 50). Only slush runs are to be expected for slopes less than 15°. Yet, since slush avalanches may originate on slopes as small as 2° [51] as a result of intensive Spring thawing, they must be considered a factor in oil spill transport and may be a factor in pipeline failures in Arctic and sub-Arctic environment.

D. VERTICAL DISPERSION OF OIL IN WATER

The principal physical mechanisms for the vertical dispersion of oil in the water column are diffusion, wave-induced vertical orbital motion, physical effolding by breaking waves, and sedimentation. Of these processes, diffusion and sedimentation are the best understood, at least in principle, with very little known about the mechanisms of vertical dispersion of surface pollutants, such as oil, due to orbital motion and wave effolding. Sedimentation is discussed in detail in Part E-1-d; diffusion is reviewed below.

The most complete attempt to mathematically model diffusion reported in the literature is by Lassieter, et al.,[52] who formulated a simple model based on the classical diffusion equation. The air-oil-water system is modelled as a five layer one-dimensional system consisting of a turbulent air layer, laminar air boundary layer, oil (slick) layer, laminar water boundary layer, and turbulent water layer. In each of these layers, the concentration of any particular compound of interest is governed by the classical diffusion equation subject to mass continuity and concentration balance equations across each interface. The system of equations is coded as a set of finite difference equations for numerical computations.

With the use of the numerical model, the diffusion process for benzene and naphthalene is studied under various postulated conditions

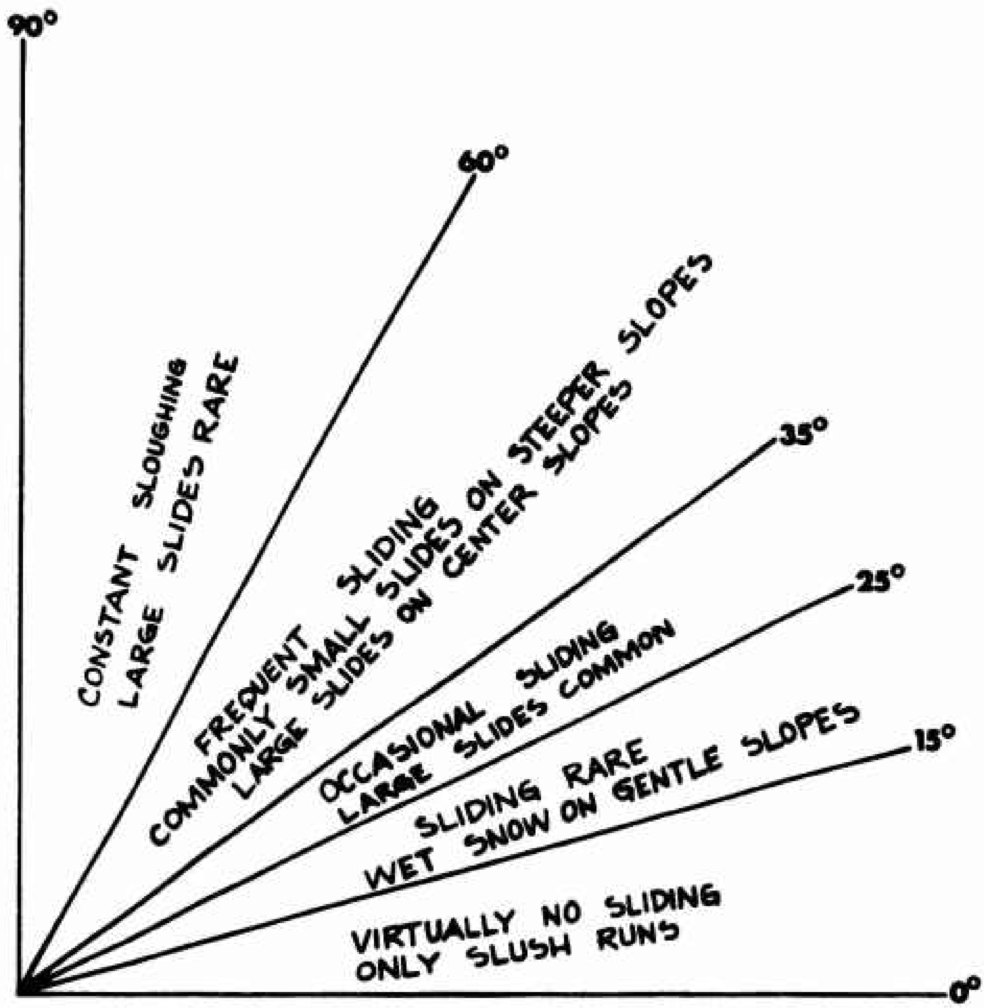


FIGURE 5-16. TYPICAL VARIATIONS OF SLIDE ACTIVITY WITH SLOPE ANGLE.

SOURCE: U.S. Department of Agriculture, *SNOW AVALANCHES. A HANDBOOK FOR FORECASTING AND CONTROL MEASURES*, Forest Service, Agriculture Handbook No. 194, 1961.

Assumptions are required for the thicknesses of the five layers, the diffusivities in each layer, the solubility ratios between oil and water and oil and air, and the evaporation (absorption) rates controlling transport across the outermost boundaries of the system. Their conclusions drawn from the numerical experiments may be summarized as follows:

1. Using best-guess values for the physical parameters, it is concluded that for a 0.1-cm thick slick, 90 percent of benzene will leave the slick in three hours and 94 percent in six hours, with the bulk of the benzene going into the atmosphere. Concentrations of 1 ppm of benzene to depths of 3 to 4 meters under the slick can be generated for approximately 12 hours. The results are sensitive to slick thickness and to duration of slick residence over a given column.

2. Naphthalene diffuses into the water column to a much lesser degree than benzene, remaining in the slick for prolonged periods of time. For this compound, sedimentation and other physical mechanisms are more important than diffusion for vertical dispersion in the water column.

3. The results of the study indicate that migration of benzene from oil to water to air depends strongly on the slick thickness and the thickness of the boundary layer beneath the slick.

From analysis of these theoretical results, one concludes that much further study of the physical variables involved in the system is necessary before more definitive conclusions concerning the diffusion process can be drawn. However, one does derive a lower bound to water column contamination of the order of 5 m or less due to the process of diffusion.

Field studies during the Chedabucto Bay spill incident report oil particle distributions in the water column to depths of 50 m .[53] In addition, Blumer[54] observed naphthalene in 6 m of water, whereas the calculations of Lassiter, et al., show maximum naphthalene diffusion depths of less than 2 m. Thus, one concludes that in all but quiescent waters, other physical dispersion mechanisms are probably of far greater importance than diffusion. Unfortunately, other than sedimentation, very little is known about these processes at this time.

E. WEATHERING OF OIL

The weathering or aging of oil in the environment is governed by three types of processes: (1) physical processes such as evaporation, dissolution, emulsification, absorption; (2) chemical processes such as direct oxidation and reduction reactions in the water column, and (3) biological processes such as aerobic and anaerobic microbial degradation. Of these, physical processes altering viscosity, density, volatility, etc., are of major importance immediately after the spill, whereas chemical and biological processes, which change the percent content of saturated hydrocarbons, aromatic hydrocarbons, polar nitrogen, sulfur, oxygen (NSO) compounds, etc., influence the characteristics of the oil over a long period of time. The latter are, in all likelihood, the final determinants of the eventual fate of the spilled oil.

To estimate the effects of all weathering processes, the initial composition of the spilled crude or oil product is of primary importance. Unfortunately, the chemical composition of crude oils is quite complex and varies greatly among oils of different geologic and geographic origin, as well as being influenced by processing, if any, prior to transshipment via tanker or pipeline. Thus, to evaluate a specific hypothetical pollution incident, it is necessary to obtain the properties of the material which may be involved in the spill. The ranges of known values for crude oil (Koons[55]) are indicated as follows:

1. Specific gravity, as a function of temperature (0.700 to 1.000).
2. Viscosity, as a function of temperature (0.6 to 1,000 centipoise).
3. Surface tension (20 to 37 dynes/cm).
4. Pour temperature (-65°F to +65°F).

Also, a rough indication of the chemical composition of the crude to be produced and/or transshipped should be known according to (a) molecular size, and (b) molecular type. For example, Koon[55] defined "average" properties of crude by molecular size as follows (carbon number range shown in parenthesis): gasoline (C_5 - C_{10}) 30%, kerosene (C_{10} - C_{12}) 10%, light distillate oil (C_{12} - C_{20}) 15%, heavy distillate oil (C_{20} - C_{40}) 25%, and extremely heavy residuum oil (> C_{40}) 20%. By molecular type, the breakdown is as follows for the "average" crude: paraffin hydrocarbons (alkanes) 30%, naphthene hydrocarbons (cycloalkanes) 50%, aromatic hydrocarbons 15%, and polar nitrogen, sulfur and oxygen containing compounds (NSO's) 5%. Specific crudes will differ substantially from these values, hence the importance of establishing the properties of the oil that may be spilled in a given area.

In addition to crude, evaluation of potential spill effects must also consider such products as bunker C or #6 fuel oil, diesel or #2 fuel oil, gasoline and kerosene. Bunker C or #6 fuel oils are the heaviest distillate fractions of petroleum with typical physical properties as follows:[55] specific gravity approximately 1.00, viscosity of the order of 1,000 centipoise (at 100°F) and pour point approximately 70°F. By average molecular type, bunker C contains 15% paraffins, 45% naphthenes, 25% aromatics, and 15% polar NSO's, with the great majority of compounds in the $> C_{30}$ range. For diesel or #2 fuel oils representing the intermediate distillate fractions, the specific gravity is in the range of 0.825 to C.850, viscosity about 40 centipoise (at 100°F) with pour point at -5°F. Chemically, the majority of compounds are in the C_{12} - C_{25} range, with emphasis on C_{15} - C_{16}, with molecular-type breakdown of 30% paraffins, 45% naphthenes, and 25% aromatics. The lightest distillates are gasoline (C_5 - C_{10}) and kerosene (C_{10} - C_{12}) with specific gravity of about 0.700 to 0.800 and viscosity in the range < 2 centipoise (at 100°F). Average molecular-type breakdown for (virgin) gasoline is 50% paraffins, 40% naphthenes, and 10% aromatics (for blended gasolines, the aromatics may be as high as 30%). For kerosene, the molecular-type breakdown is 35% paraffins, 50% naphthenes, and 15% aromatics.

Again, it is emphasized that these are only rough, representative characterizations and that to imrpove calculations of spread, dispersion, and eventual fate of a specific spill, one requires a knowledge of the specific properties of the spilled material. The range of values for the kinematic viscosity of some crude oils and emulsions is shown in Figure 5-17. Furthermore, the operational response of the Coast Guard would be greatly facilitated if the above properties were on file for all commonly handled products in a given area.

Specific weathering processes are now discussed in more detail.

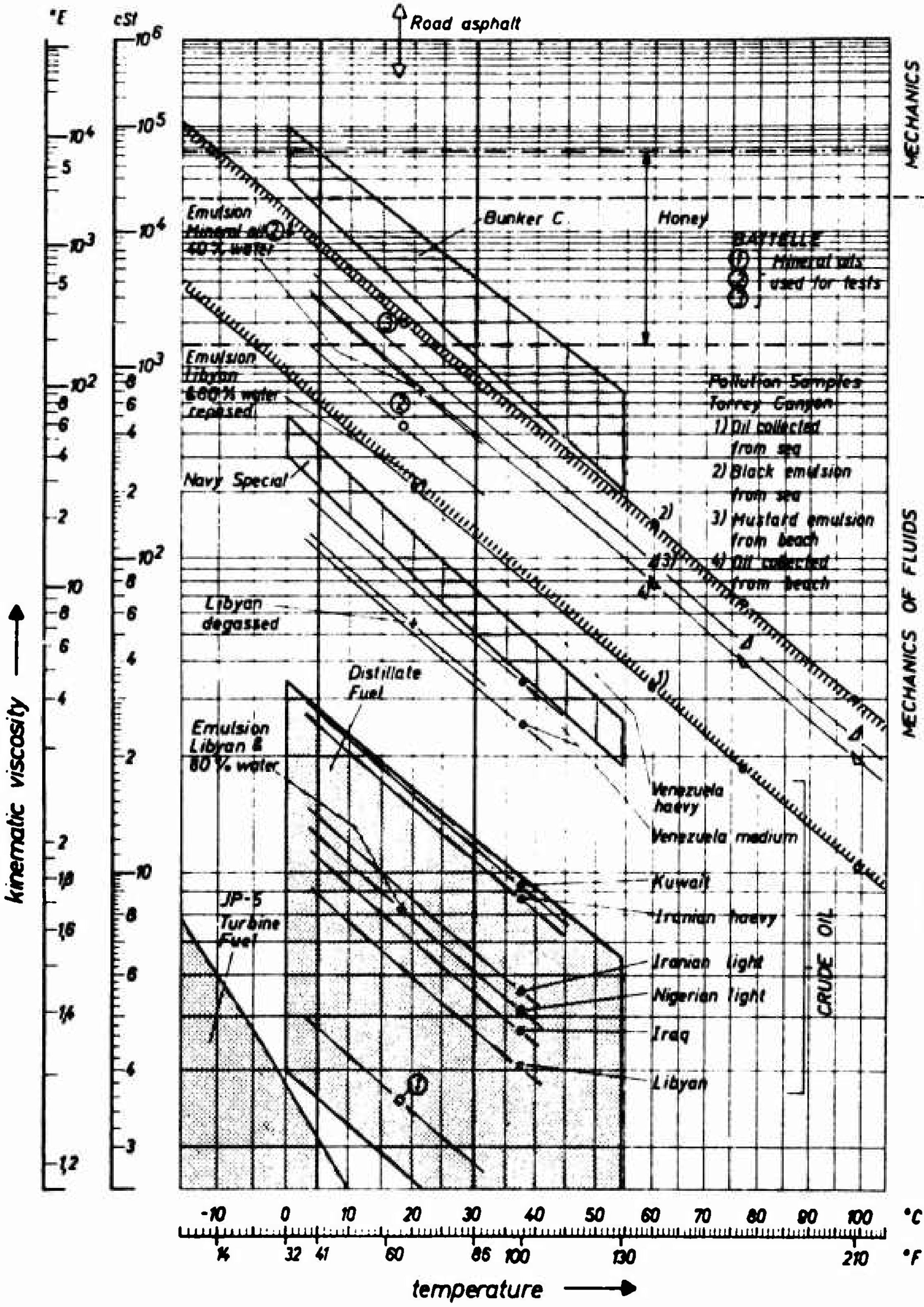


FIGURE 5-17. KINEMATIC VISCOSITIES OF SOME CRUDE OILS AND EMULSIONS

SOURCE: Asper, J.J., and P. Bolli, "New Device for Removing Oil Slicks from the Surface of Water, " *PROCEEDINGS 1973 CONFERENCE ON PREVENTION AND CONTROL OF OIL SPILLS*, API, Washington, D.C.

(1) PHYSICAL WEATHERING

(a) EVAPORATION

Of primary importance to physical weathering is evaporation; the process by which low-molecular-weight compounds are volatilized into the atmosphere. In general, one can conclude that for any oil product, the greater the rate and extent of spreading, the greater the evaporation. Consequently, the same oil, say Prudhoe Bay crude, will experience more rapid degradation by evaporation at the southernmost spill sites than at Prudhoe, where it will not spread to the same thin film (c.f. discussion on spreading of oil on ice or freezing water, Part C). In addition to the influence of the exposed surface area and thickness of the oil slick, evaporation will be affected by wind (atmospheric turbulence), possible covering by or emulsification with blowing snow, the boiling point distribution of the low molecular weight compounds and the temperature of each layer of the air-oil-water (or ice, land) system.

The study of evaporation of volatile compounds of oil was initiated by Blokker[1] with extensions by Hoult[31,56] and Smith and MacIntyre.[57] Measurement of evaporation rates from oil slicks on the open sea have also been reported by Sivadier and Mikolaj.[58] Hoult[56] has argued that the evaporation rate is proportional to the friction velocity in the atmospheric boundary layer; however, the utility of this result is seriously impaired by the lack of knowledge concerning actual distribution and magnitude of the friction velocity for various real surface conditions, such as ice or rough water. However, from simulated evaporation experiments[55] and crude field observation, one may conclude that all hydrocarbons containing less than 15 carbon atoms (boiling point < 250°C) will be volatilized fairly readily except under stringent Arctic conditions. From this observation, one may conclude that approximately 50 percent of the hydrocarbons of the "average" crude discussed above will evaporate. Little detail is known about the chemical composition of Prudhoe Bay crude oil. Apparently, only the C_1 - C_6 alkanes have been analyzed in detail.[59] Routine analysis[59-61] indicated that total gasoline and naphtha fraction is about 20 percent by weight, and it is only this fraction that would evaporate to a significant extent during the first 10 days or so after a spill. The remaining 80 percent of the crude would undergo little change in composition; this fraction contains about 30 percent aromatics. In the case of bunker-C, on the order of 10 percent or less of the hydrocarbons will be volatilized. For diesel, the percent could go as high as 75 percent, and almost complete evaporation of gasoline and/or kerosene could be expected under most conditions, leaving only a slight residue of the original product in the water or sediments.

Experimental work applicable to the present study is that of Kinney, et al.,[62] who conducted a small experimental spill of Cook Inlet crude and the experiments of Glaeser[32] and McMinn.[33] Kinney, et al.,[62] found that all light components up to C_8 evaporated within 8 hours, whereas components heavier than C_{14} were almost completely retained. Glaeser's results indicated that all fractions lighter than C_{10} will evaporate in a period of the order of five days in the Arctic.

EFFECTS ON DENSITY AND SURFACE TENSION

The experimental results of Glaeser[32] indicated that the density and air-oil interfacial surface tension exhibit little change over a period of a few days. The specific gravity increased from 0.89 to about 0.91 or 0.93

during the first week or so. Hoult[31,56] derived a theoretical prediction of the time variation of density based on both a simple two-component theory and a theory based on continuous distribution of fractions. His results are shown in Figure 5-18 (taken from USCG Report CG-D-96-75) where the theory is compared to the observations of Glaeser and Vance.[11]

EFFECTS ON VISCOSITY

Whereas the density and surface tension change relatively little, the viscosity of Prudhoe Bay crude may change by a factor of 3 or more during the first 24 hours and by a factor of 10 in a week. Because of the important implications of viscosity on spreading calculations as well as assessment of cleanup feasibility, the time and temperature effects are discussed in detail.

The viscosity of fresh and aged Prudhoe Bay crude oil is given in Figure 14 of Glaeser and Vance.[11] In this figure, log μ is plotted vs. log T where μ is viscosity and T is temperature. In this form, the data are unsuitable for extrapolation to the important temperature range of below $3^{\circ}C$. On the other hand, a plot of log μ vs. 1/T (where T is degrees absolute) is known to yield a straight line over a considerable range. Such a plot of Glaeser and Vance's data yields the following results:

TABLE 5-4
VISCOSITY AS A FUNCTION OF TEMPERATURE

T		
$^{\circ}C$ (1)	$^{\circ}F$ (2)	μ, CENTIPOISE OF PRUDHOE BAY CRUDE OIL (3)
-10	14	770
-5	23	420
0	32	240
5	41	140
10	50	82
15	59	50

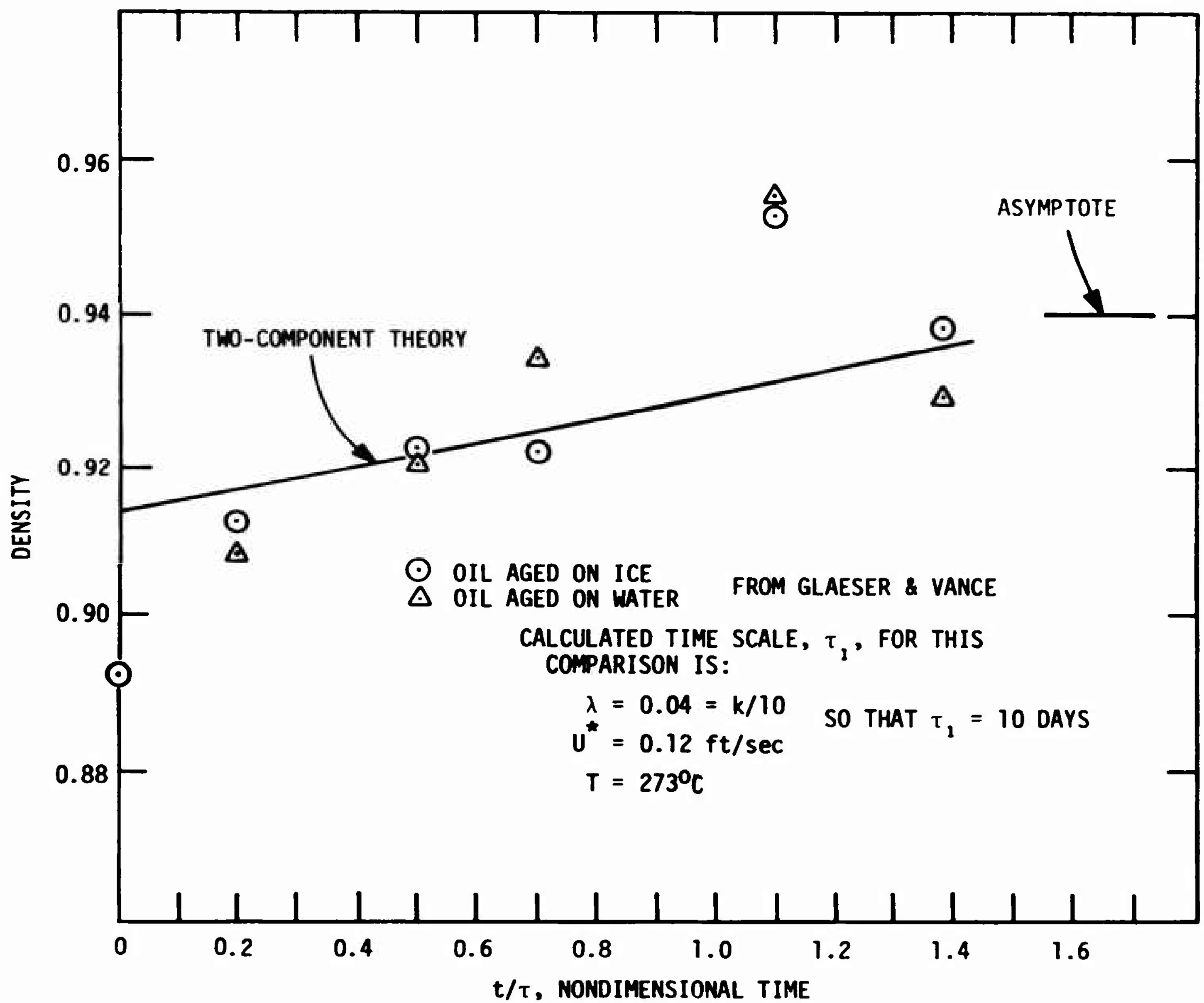


FIGURE 5-18 VARIATION OF DENSITY AS A FUNCTION OF TIME FOR OIL AGED ON ICE AND WATER

The results for $T < 0^oC$ are considerably less than would be found by extrapolation of Figure 14 of Glaeser and Vance.[11]

CHANGE OF VISCOSITY WITH TIME

It is possible to calculate from theory above the change of viscosity with time following a spill. Fortunately, however, Glaeser and Vance presented data for one set of conditions, and theory can be used to extrapolate the data to other conditions.

Glaeser and Vance report the change of viscosity with time of a controlled spill of Prudhoe Bay crude on a melt pond. The slick was about 5-mm thick, and observations were made for a period of seven days during which the conditions were approximately as follows:

air temperature	31 - 52, average about 38^oF
wind speed	10 knots
water temperature	29 - 32^oF
oil temperature	31 - 60, average about 45 - 50^oF

In the absence of direct sunlight, and if the wind velocity is not very high (less than about 30 knots), the temperature of an oil slick will be much closer to the water temperature than the air temperature because the heat transfer coefficient from slick to water is on order of magnitude greater than the coefficient from slick to air. With direct sunlight, the slick will be heated several degrees above the water temperature.

Glaeser and Vance's data were taken in direct sunlight, and they reported that the slick temperatures "varied up to several degrees above the air temperature in bright, clear days." It is unfortunate that they did not report slick temperatures since the vapor pressure and hence evaporation rate is strongly temperature-dependent. In the calculations that follow, their oil temperature has been taken to be constant at 8°C. Their data, extrapolated to a viscosity at 0°C, are as follows:

TABLE 5-5
VISCOSITY AS A FUNCTION OF TIME

DAYS (1)	μ AT 0°C or 32°F CENTIPOISE (2)
0	240
2	1,500
5	1,900
7	2,200

To extrapolate these data to other conditions, the following assumptions were made:

1. The rate of evaporation is proportional to the wind speed. This cannot be quite correct. On a flat surface, the rate varies as the 0.8 - 0.88 power of velocity. On water, however, surface roughness increases with speed which would increase the velocity exponent. Hence, taking the rate to be directly proportional to wind speed seems reasonable.

2. The rate of evaporation is directly proportional to the "average" vapor pressure at any time, which in turn is determined by the slick temperature. By examining the vapor pressure of several typical components of oil, the following table of relative vapor pressure vs. temperature has been devised:

TABLE 5-6
VAPOR PRESSURE AS A FUNCTION OF TEMPERATURE

T ^{o}F (1)	(VAPOR PRESSURE)/(VAPOR PRESSURE AT 50^{o}F) (2)
20	0.32 $\pm$ 0.10
25	0.39
30	0.48 $\pm$ 0.08
35	0.59
40	0.71
45	0.85
50	0.00

This table was used to extrapolate the data of Glaeser and Vance to other temperatures. For example, Glaeser and Vance's data were taken at about 50^{o}F, so that if the oil were at 30^{o}F, it would take 1/0.48 or about twice as long to reach the same viscosity as shown in Table 5-5.

3. In the absence of direct sunlight, the slick assumes the temperature of the water. With direct sunlight, it is 15^{o}F above the water temperature.

4. The time to reach a given viscosity is inversely proportional to the film thickness. This is approximate but reasonable. It would be exact if the oil film were always of uniform composition (well-mixed).

With the above assumptions, the data of Table 5-5 can be extrapolated to other conditions, and the results are shown in a series of graphs (Figures 5-19 - 5-21). It should be kept in mind that these graphs are very approximate. They are based upon one set of data for one set of conditions. The data were taken on a small pond where wave action was small. The effect of wave action on the evaporation rate is accounted for in only a crude way in the first assumption.

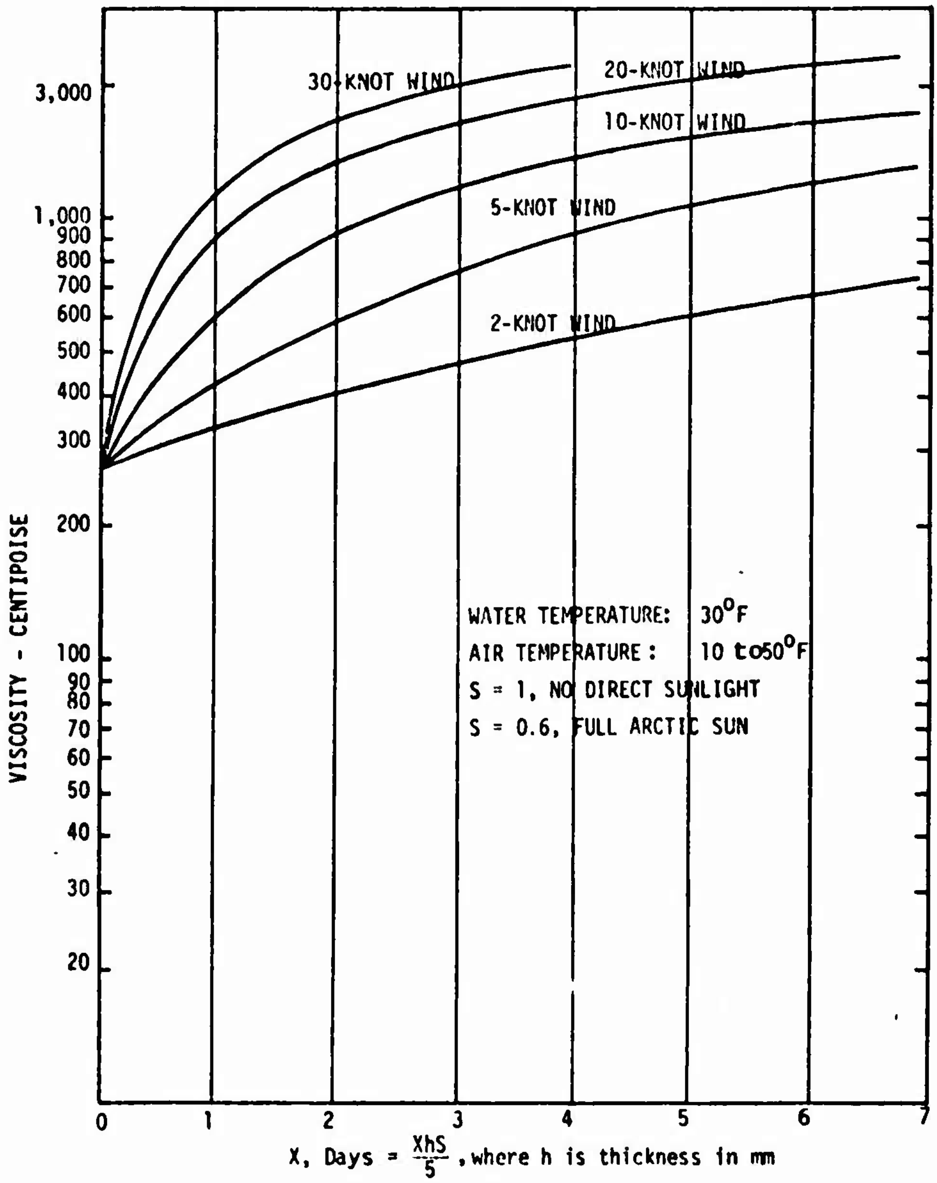


FIGURE 5-19. VISCOSITY OF NORTH SLOPE CRUDE SPILLED ON WATER.

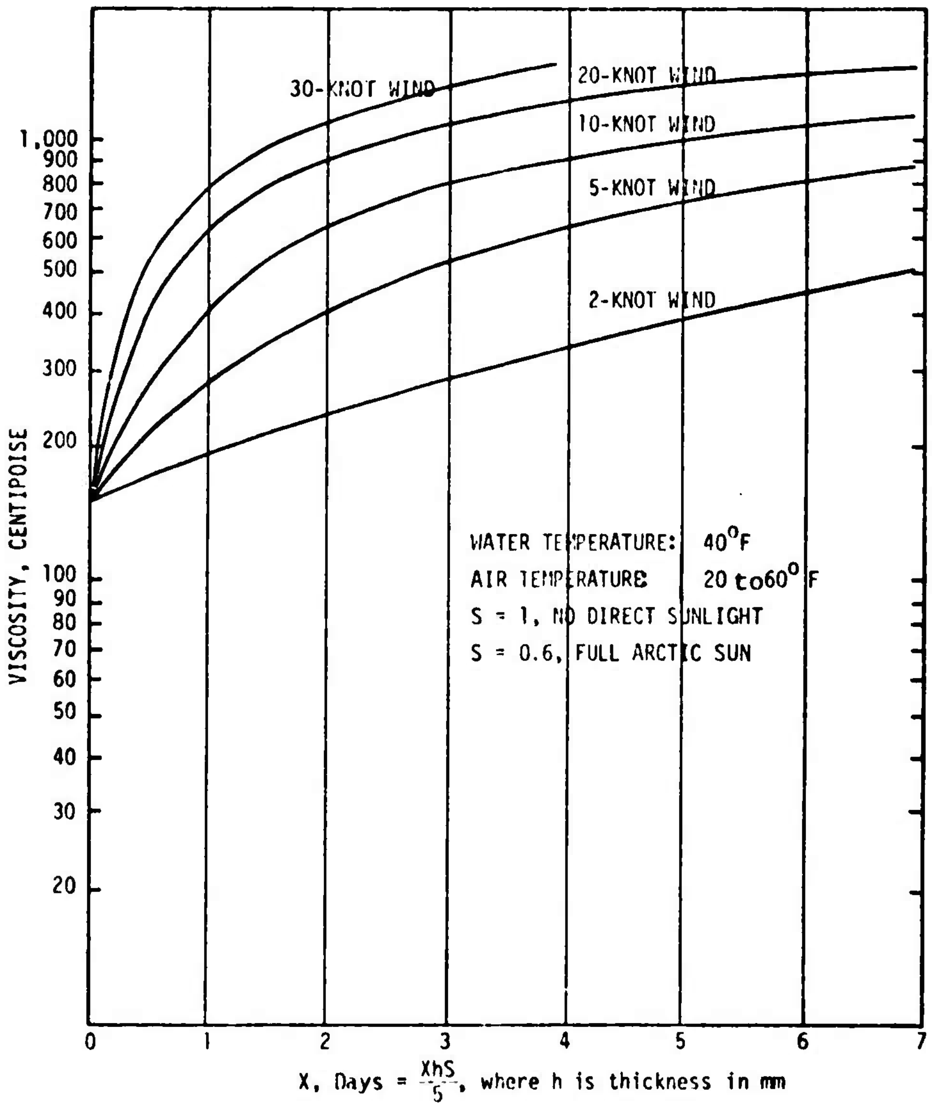


FIGURE 5-20 .VISCOSITY OF NORTH SLOPE CRUDE SPILLED ON WATER.

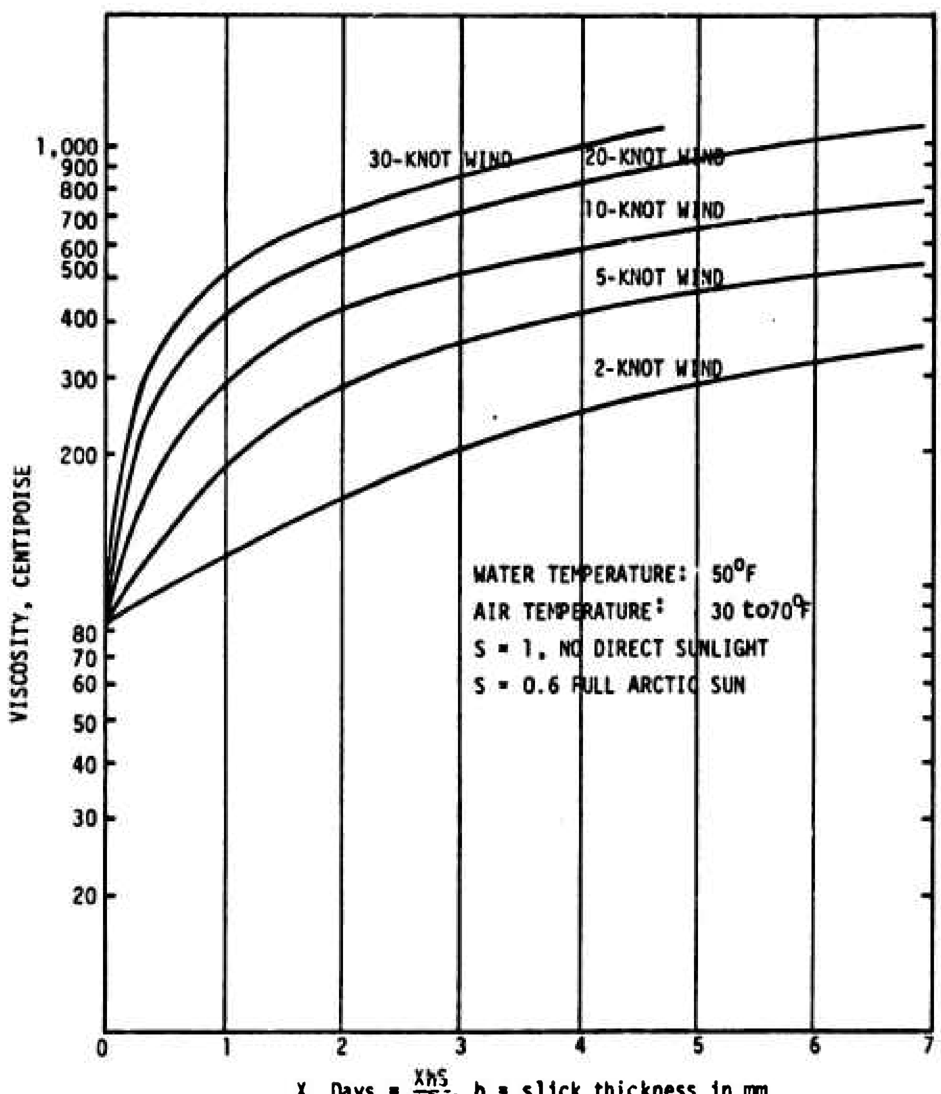


FIGURE 5-21. VISCOSITY OF NORTH SLOPE CRUDE SPILLED ON WATER.

(b) SOLUTION

If oil is spilled on water, dissolution of low-molecular-weight hydrocarbons as well as some of the polar non-hydrocarbon compounds in the water will occur. The rate of this process is governed by the turbulence characteristics of the water surface layer as well as the properties of the oil, i.e., chemical composition, viscosity, surface tension, etc. Thus, the amount of material dissolved in the water column will be affected by the evaporation processes discussed above. The solution process has long-term aspects as well as short-term since the various oxidation processes (discussed below) produce polar compounds from hydrocarbon in the oil.

The water solubility of hydrocarbons has been studied by McAuliffe.[63] From the solubility data, one can conclude that the light saturated and aromatic hydrocarbons (up to about C_{10}) will be removed from the slick via solution rather rapidly. In addition, one expects that higher molecular-weight hydrocarbons and oxidation products produced by biological and non-biological processes will also be gradually leached out by the sea water. Substantiation of the results of McAuliffe is provided by the work of Zarella, et al.,[64] McAuliffe,[65] Boylan and Tripp,[66] and Frankenfeld,[67] who found presence of higher molecular-weight compounds. Burwood and Speers[68] reported on experimental studies confirming that the major initial process appears to be the selective dissolution of aromatic hydrocarbon components; in addition, they reported on the inclusion of oxidation products in the solution.

(c) EMULSIFICATION

One may expect that agitation of the oil-water mixture which may occur under storm or severe tidal turbulence conditions would accelerate the solution processes. In addition, emulsification forming either oil-in-water or water-in-oil emulsions will occur. The degree to which emulsification will occur depends on the amounts of surface-active agents in the oil. For example, certain California crudes emulsify quite readily due to a high concentration of high-molecular-weight cyclic carboxylic acids as discussed by Seifert and Howells.[69] The emulsification process is also discussed by Berridge, et al.,[70] and Mackay, et al.[71] Although the process is reasonably well understood, in order to predict the degree to which emulsification will occur in any given incident, the composition of the crude oil involved must be known. This again underscores the need for readily accessible information on oil properties.

(d) SEDIMENTATION

Oil slick weathering will also be influenced by physical removal of oil particles by sinking as a consequence of an increase in density. Such density increase may be a result of evaporation and dissolution, uptake by the oil of particulate matter either of organic or inorganic origin, agglutination of dispersed particles followed by combination with organic or inorganic particles and absorption of dissolved compounds onto particulate matter. An excellent discussion of the role of sedimentation in the weathering process is given by Gebelein.[72] Most of the conclusions drawn about sedimentation in the open-water environment are speculative in nature since few direct observations of suspended oil particles and bottom sediment depositions of oil have been reported in the literature. The simple assumption that any particulate matter in the water column will act in the same way to remove oil compounds is questioned by Feldman.[73] Background material forming a basis for studying site-specific sedimentation processes is given in a review paper on intercalation of organic molecules, including petroleum fractions, by Whitehouse.[74]

The process of sedimentation in intertidal environments is somewhat better understood and bears more detailed discussion because of the implication for intertidal zone cleanup operations, to be discussed in Section 6-G. Intertidal zones for this discussion may be classified as beaches, tidal flats, and rocky shores. The dynamics of sedimentation and subsequent evolution of deposited oil fractions are best discussed in terms of low-energy shorelines and high-energy shorelines.

Sandy beaches may be either low-energy or high-energy environments, depending on topographical configuration (e.g., long, exposed beaches or protected lagoon beaches) and may change from one to the other, depending on the season. Typically, cycles of sediment deposition and erosion go on on a short-term tidal cycle basis and a long-term seasonal cycle basis. Periods of deposition and erosion longer than seasonal also exist for certain beach and offshore shelf configurations. The range of buildup and erosion for all these cycles is from a few millimeters to a meter, with the larger values associated with the longer periods. Thus, extensive reworking of beach sediments will occur on a seasonal basis.

The nature and disposition of oil compounds on or in a beach will be governed by the physical characteristics of the oil as it comes ashore as well as by the properties of the beach sediments themselves. Beach sediments are characteristically well-sorted of both high porosity and high permeability, with low tide sediments being water-filled and high tide sediments characterized by air-filled voids for much of the tidal cycle. Whether the oil comes ashore as a slick or viscous emulsion or as dispersed oil particles, the effect of wave action during rising tide will be to concentrate oily material near the high tide line. As the tide recedes, the stranding of oily material in the upper tidal regions will result in melting and penetration of the air-filled voids by oil fractions during the low tide (Ludwig and Carter[75]) part of the cycle. Reworking of the beach by wave action during subsequent tidal cycles coats sandy particles; this coating coupled with void-filling may restrict direct penetration of subsequent oil if the particles are small, or enhance (at large particle sizes) the reworking of the oil. The detailed mechanisms of penetration, coating, and reworking are not well known for low-temperature, low-pressure processes such as on the beaches (as opposed to oil movement through sand-sized sediments at high temperatures and processes). Guard and Cobet[76] reported on the fate of bunker fuel in beach sand at three beaches in the San Francisco area which were polluted by the January 1971 Standard Oil tanker collision in San Francisco Bay. Their results implied a gradual decrease in the oil content of the beaches at the high tide level, but no decrease in total concentration at the low tide level over a 120-day period. Incidentally, they noted that Great Beach at San Francisco had been extensively altered by wave action between samplings on April 6th and April 27th, 1971, with resultant removal of 2 to 3 ft of beach material from the sampling area. The ultimate fate of oil particles in a beach will depend on microbial action (if any), the history of sediment transport, and the nature of the tidal hydraulic pump which moves water through the sediments (sediment flushing action).

Whereas beaches may be either high energy or low energy (in protected lagoons), tidal flats and salt marshes are examples of strictly low-energy shoreline. The sediments in such areas are typically much more fine-grained and higher in organic content,[77] with high porosity but low permeability. With a lack of seasonal cycles of erosion and deposition, and minimal tidal cycle action, any oil contaminated areas are not likely to be subject to extensive reworking. The high rates of sedimentation in these areas will rapidly (order of a few months) bury any oil that encroaches. Extremely long life and low biological degradation (due to low oxygen content in the sediments) may be expected in these areas (Blumer,[78] Baker[79]). The tidal pump action is very low level, causing oil fractions to be extracted from the tidal flats and salt marshes at a slow rate over a long period of time.

Typical of high-energy shorelines are beaches exposed to pounding surf and rocky shorelines. The behavior of beaches has already been discussed, so that only the new features introduced by rocky shorelines need be addressed. The principal effects here are coating and some penetration, if the rocks are porous and/or permeable. Typically, in the low to middle tidal range, the rocks are algae coated, which will be oiled. The cycle then usually is one of algal and associated biological grazing community death, subsequent excessive algal growth, and a slow return to equilibrium as the grazing population replenish themselves.

Substantiation of the above conclusions about the fate of oil in low to high-energy shorelines is provided by the results of Rashid[80] who studied the degradation of bunker C in Chedabucto Bay 3.5 years after the spill. The environmental conditions may be expected to be more representative of Arctic and sub-Arctic conditions than other reported spill results. Rashid analyzed samples from representative low, moderate, and high-energy environments and concludes that in low to moderate energy shorelines, total loss of saturates and aromatics of bunker C is less than 5 percent. In the high-energy samples, the saturated and aromatic hydrocarbons were reduced to 34 percent compared with 51 percent in reference bunker C gathered at the time of the spill. The non-hydrocarbon fraction for these samples showed an increase from 49 to 66 percent for the reference, indicating that degradation processes were active as well as physical reworking.

(2) CHEMICAL WEATHERING

An understanding of chemical weathering requires consideration of atmospheric oxidation of the oil on the surface of water (ice, land), oxidation reactions in the water column, and (possibly) reduction reactions which may occur in low-oxygen-content water layers as the oil is transported (through sedimentation or sinking) to near the bottom. Of primary importance is photo-oxidation (auto-oxidation) which is a spontaneous reaction of a compound with molecular oxygen at moderate temperatures. Since most auto-oxidations are accelerated by increasing temperatures as well as by light, one would expect that these processes are less significant in the overall weathering of oil in the Arctic region than in more temperate zones. The photo-oxidation process is discussed by Burwood and Speers,[68] who cite the relevant literature on the subject. Unfortunately, most of the reported work is addressed to Middle East crude oils; since, once again, the oxidation process is strongly composition-dependent, only general conclusions concerning the importance of this process to the weathering of (local) oil in Arctic conditions may be drawn.

(3) BIOLOGICAL DEGRADATION

The role of biological degradation in the long-term evolution of oil compounds in the environment has been extensively studied in recent years. As with most aspects of oil pollution, the literature is voluminous and the extraction of practically useful information is becoming more and more difficult. Since oil biodegradation has been studied since the turn of the century, one needs a convenient starting point for evaluating the state-of-knowledge in this area. Such a starting point is furnished by the proceedings of a workshop on microbial degradation of oil pollutants[81] held in Atlanta, December 1972. For bibliographical material, the most recent published list on oil pollution and oil decomposing bacteria is Reference 82. In this section, the status of current knowledge about biodegradation in Arctic and sub-Arctic environments will be briefly reviewed.

When discussing the microbial degradation of oil in any environment, one must keep in mind that bacteria are substrate-specific, i.e., only a limited number of hydrocarbons can be utilized by any one special bacterial strain, so the term "oil decomposing bacteria" is quite misleading. Furthermore, even given the existence of bacteria mixtures capable of degrading oil compounds, the extent to which degradation will occur is governed by the oxygen, nitrogen, and phosphate salt content of the environment. Temperature also influences oil degradation in two ways: at low temperatures, the low-boiling fractions take longer to evaporate and the activity of the bacteria is slowed down. However, it has been demonstrated (Zobell and Agosti,[83] Zobell,[84] Robertson, et al.,[85] Atlas and Bartha,[86] and Button[87]) that even for low temperatures characteristic of the aquatic environment of

Alaska, say $\sim$ - 1^{o}C, oil-degrading activity of microorganisms still exists. However, the microorganism species capable of oxidizing oil at near 0^{o}C do so only at 5 to 10 percent the rate of oxidation by species active at 25^{o}C. There are some indications that some of these low-temperature species may be killed when the temperature rises to higher values, say 25^{o}C; however, the studies of Traxler[88] of psychrophilic bacteria from Chedabucto Bay indicated that large numbers do survive the seasonal temperature cycles.

Another aspect that must be considered is the influence of other organisms feeding on the bacteria which are feeding on the oil; such activity was noted by Gunkel,[89] who observed huge numbers of Protozoans feeding on the bacteria, causing cessation of oil degradation.

Biodegradation of crude oil in the terrestrial environment is currently under study in connection with the research program funded by the Environmental-Social Committee Northern Pipelines Task Force on Northern Oil Development, Government of Canada. The results of ongoing research are reported by Cook and Westlake[90] and Parkinson.[91]. The thesis has been advanced by these researchers that biodegradation is facilitated by improving the nutritional status of the environment; substantiation of this thesis is provided by the results of Reference 90 where they noted that:

> "application of fertilizer (NH_4NO_3 and Na_3PO_4) showed remarkable increase in the rates of n-paraffin degradation."

Data obtained in studies of oil degradation in sea water (Atlas and Bartha[92] and Reisfield, et al.[93]) indicated that fertilizer also accelerated the degradation in an aquatic environment. The results of Cook and

Westlake[90] show that although n-paraffins are microbially degraded in Arctic soils, the indigenous supply of nutrients such as nitrogen and phosphorus are rapidly depleted by the biological activity and hence fertilization is required to effect rapid rates of degradation. Soil temperature and moisture are shown to have important effects on the degradation process.

These results indicate that fertilization as well as bacterial seeding of spills may stimulate the degradation process. However, before proceeding with development of bacterial cultures to counteract oil spill effects, the ultimate effects of the introduction of bacterial cultures on the environment should be carefully studied. The question of whether or not such cultures die out after utilization of the oil or seek other habitats in the biosphere should be clearly established before consideration of introducing "foreign" bacteria into the oil-affected environment.

In summary, although it is clearly evident that microbial degradation is a viable process in the long-term evolution of an oil spill, either in our aquatic or terrestrial environment, insufficient knowledge exists as to actual rates and degree of degradation to be expected. Specific studies of oil compounds in selected locations not subject to extensive physical reworking, i.e., tide flats, marsh land, tundra, etc., should be carried out over the next few years to aid in evaluation of the biodegradation mechanism. Laboratory measurements and carefully controlled cultures will help in broadening the understanding of the biodegradation process, but direct extrapolation of these results to the "real world" could be extremely misleading. The use of "non-mobile" study areas is necessary to separate flushing and/or transport mechanisms from biodegradation activity; for example, in the background study of available knowledge concerning the Alaskan Arctic coast,[94] the authors quoted Kinney's 1970 studies in Cook Inlet as showing that biodegradation of Cook Inlet crude oil is essentially complete in two to three months. However, the complete tidal flushing time of the Inlet is of the order of 10 to 12 months, hence, the dilution and transport mechanisms are more likely responsible for the reduction of oil compound concentrations than biodegradation.

SECTION 5. REFERENCES

1. Blokker, P. C., "Spreading And Evaporation Of Petroleum Products On Water," *PROCEEDINGS OF THE 4TH INTERNATIONAL HARBOR CONF.*, June 22 thru 27, 1964.

2. Jeffery, P. G., *LARGE-SCALE EXPERIMENTS ON THE SPREADING OF OIL AT SEA AND ITS DISAPPEARANCE BY NATURAL FACTORS,* in: "Proceedings Of The Joint Conference On Prevention And Control Of Oil Spills," March 13 thru 15, 1973.

3. Fay, J. A., "Physical Processes In The Spread Of Oil On A Water Surface," *PROCEEDINGS OF THE JOINT CONFERENCE ON PREVENTION AND CONTROL OF OIL SPILLS,* API, June 1971.

4. Hoult, D. P., "Oil Spreading On The Sea," *AM. REV. FLUID MECH.*, pages 59-64, 1972.

5. Fannelop, T. K. and G. D. Waldman, *THE DYNAMICS OF OIL SPILLS OR CREEPING CRUDE,* Am. Inst. of Aeronautics and Astronautics, Paper No. 71-14, January 1971.

6. Fannlop, T. K. and G. D. Waldman, "Dynamics Of Oil Spills," *AIAA JOURNAL*, pages 506-510, 10 April 1972.

7. Mackay, D., M. E. Charles, and C. R. Phillips, *THE PHYSICAL ASPECTS OF CRUDE OIL SPILLS ON NORTHERN TERRAIN,* Northern Pipelines Task Force On Northern Oil Development, Report No. 73-42, January 1974.

8. Hoult, D. P. and Suchon, W., *THE SPREAD OF OIL IN A CHANNEL,* Fluid Mechanics Laboratory, Department of Mechanical Engineering, MIT, 1970.

9. Lee, R. A., *A STUDY OF THE SURFACE TENSION CONTROLLED REGIME OF OIL SPREAD,* MS Thesis, MIT, 1971.

10. Waldman, G. A., R. A. Johnson, and P. C. Smith, *THE SPREADING AND TRANSPORT OF OIL SLICKS ON THE OPEN OCEAN IN THE PRESENCE OF WIND, WAVES, AND CURRENTS,* AVCO Systems Division, Report CG-D-17-73, July 1973.

11. Glaeser, J. L. and G. P. Vance, *A STUDY OF THE BEHAVIOR OF OIL SPILLS IN THE ARCTIC,* Commandant (DAT) USCG, Project No. 714103/A/001,003, February 1971.

12. Schwartzberg, H. G., *SPREADING AND MOVEMENT OF OIL SPILLS*, Federal Water Pollution Control Administration, Report No. PB 192852, March 1970.

13. Reisbig, R. L., *OIL SPILL DRIFT CAUSED BY THE COUPLED EFFECTS OF WIND AND WAVES*, Office of Research and Development, United States Coast Guard, Report No. CG-D-52-74, October 1973.

14. Neumann, G. and Pierson, W. J. Jr., *PRINCIPLES OF PHYSICAL OCEANOGRAPHY*, Prentice-Hall Inc., N. J., 1961.

15. James, R., *OCEAN THERMAL STRUCTURE FORECASTING*, U. S. Naval Oceanographic Office, 1966.

16. Murty, T. S. and M. L. Khandekar, *SIMULATION OF MOVEMENT OF OIL SLICKS IN THE STRAIT OF GEORGIA USING SIMPLE ATMOSPHERE AND OCEAN DYNAMICS*, in: "Proceedings Of The Joint Conference On Prevention And Control Of Oil Spills," March 13 thru 15, 1973.

17. Teeson, D, F. M. White, and H. Schenk, "Studies Of The Similation Of Drifting Oil By Polyethylene Sheets," *OCEAN ENGINEERING*, vol. 2, pages 1-11, 1970.

18. O'Brien, J. A., *WIND TUNNEL EXPERIMENTS ON OIL SLICK TRANSPORT*, Naval Civil Engineering Laboratory, Progress Report 71-1, November 1970.

19. Munday, J. C., W. Harrison, and W. G. MacIntyre, "Oil Slick Motion Near Chesapeake Bay Entrance," *WATER RESOURCES BULLETIN JOURNAL THE AMERICAN WATER RESOURCES ASSOCIATION*, vol. 6, December 1970.

20. Kaiser, R. D., et. al., *INVESTIGATION OF SURFACE FILMS--CHESAPEAKE BAY ENTRANCE*, Office of Research and Development, Region III, USEPA, EPA-670/2-73-099, February 1974.

21. Wang, Shen and Li-San Hwang, *A NUMERICAL MODEL FOR SIMULATION OF OIL SPREADING AND TRANSPORT AND ITS APPLICATION FOR PREDICTING OIL SLICK MOVEMENT IN BAYS*, Tetra Tech, Inc., Report Number TT-P-345-74-1 February 1970.

22. Murray, S. P., W. G. Smith, and C. J. Sonn, *OCEANOGRAPHIC OBSERVATION AND THEORETICAL ANALYSIS OF OIL SLICKS DURING THE CHEVRON SPILL, MARCH 1970*, Coastal Studies Institute, Louisiana State University, Tech. Report No. 87, September 1970.

23. Vagners, J. and P. Mar, *OIL ON PUGET SOUND*, University of Washington Press, Seattle, Washington, 1972.

24. Stewart, R. J., J. W. Devanney, III and W. Briggs, *OIL SPILL TRAJECTORY STUDIES FOR ATLANTIC COAST AND GULF OF ALASKA*, MIT, Report No. MITSG 74-20, April 1974.

25. Cole, C. R., H. P. Fook, and J. R. Eliason, *OIL SPILL DRIFT FORECASTING MODEL*, presented at "The 4th Joint Chem. Engr. Conf. Am. Inst. Of Chem. Engr. and Canadian Soc. For Chem. Engr.," September 9 thru 12, 1973.

26. Premack, J. and G. A. Brown, *PREDICTION OF OIL SLICK MOTIONS IN NARRAGANSETT BAY*, in: "Proceedings Joint Conference On Prevention And Control Of Oil Spills," March 13 thru 15, 1973.

27. Ferguson, H. R. P., *POINT IN POLYGON ALGORITHMS*, Urban Data Center, University of Washington, PB 219 671, April 1973.

28. U. S. Department of Commerce, NOAA, NOS, *TIDAL CURRENT CHARTS--PUGET SOUND, NORTHERN PART*, Third Edition, 1973.

29. U. S. Department of Commerce, NOAA, NOS, *TIDAL CURRENT TABLES, PACIFIC COAST OF NORTH AMERICA AND ASIA*, 1974.

30. U. S. Department of Commerce, NOAA, NOS, *UNITED STATES COAST PILOT 9, PACIFIC AND ARCTIC COASTS*, Seventh Edition, 1964.

31. Hoult, D. P., *OIL IN THE ARCTIC*, Office of Research and Development, U. S. Coast Guard, Report CG-D-96-75, March 1975.

32. Glaeser, J. L., *A DISCUSSION OF THE FUTURE OIL SPILL PROBLEM IN THE ARCTIC*, in: "Proceedings Of The Conference On Prevention And Control Of Oil Spills," API, 1971.

33. McMinn, T. J., *CRUDE OIL BEHAVIOR ON ARCTIC WINTER ICE*, Department of Transportation, USCG Project 734108, September 1972.

34. McMinn, T. J. and P. Golden, *BEHAVIORAL CHARACTERISTICS AND CLEANUP TECHNIQUES OF NORTH SLOPE CRUDE OIL IN AN ARCTIC WINTER ENVIRONMENT*, API, 1973.

35. Ramseier, R. O., *OIL POLLUTION IN ICE INFESTED WATER*, Intl. Sympos. On Ident. And Meas. Of Envion. Pollulants, 1971.

36. Ramseier, R. O., G. S. Gantcheff, and L. Colby, *OIL SPILL AT DECEPTION BAY, HUDSON STRAIT*, Scientific Series No. 29, Inland Waters Directorate Water Resources Branch, Canada, 1973.

37. AIDJEX (Arctic Ice Dynamics Joint Experiment), Division of Marine Resources, University of Washington.

38. Canadian Beaufort Sea Project, Marine Sciences Directorate Pacific Region, 1230 Government Street, Victoria, B. C., Canada.

39. Campbell, W. and S. Martin, "Oil And Ice In The Arctic: Possible Large Scale Interactions," *SCIENCE*, 181, 1973.

40. Ayers, R. C., H. O. Jahns, and J. L. Glaeser, "Oil Spills In The Arctic Ocean: Extent Of Spreading And Possibility Of Large-Scale Thermal Effects," *SCIENCE*, 186, 1974.

41. Martin, S. and W. Campbell, "Reply to Ayers et. al.," *SCIENCE*, 186, 1974.

42. Parmerter, R. R. and M. D. Coon, "Model Of Pressure Ridge Formation In Sea Ice," *J. GEOPHYS. RES.*, 77, 1972.

43. Forrester, W. G., "Distribution Of Supended Oil Particles Following The Grounding Of The Tanker Arrow," *J. MAR. RES.*, 29, 1971.

44. Bell, W. L., *AN OIL-UNDER-ICE EXPERIMENT, MAY 1974*, a talk presented at a meeting of the Beaufort Sea Project in Victoria, B. C., 19 December 1974.

45. Coachman, L. K., K. Aagaard, and R. B. Tripp, *BERING STRAIT: THE REGIONAL PHYSICAL OCEANOGRAPHY*, University of Washington Press, Seattle, Washington.

46. Mountain, D. G., *BERING SEA WATER ON THE NORTH ALASKAN SHELF*, PhD Thesis submitted to the University of Washington, Department of Oceanography, November 1974.

47. Wolfe, L. S. and D. P. Hoult, "Effects Of Oil Under Sea Ice," *J. GLACIOL.*, 13, 1974.

48. Brown, R. F., *OIL UNDER WINTER SEA ICE*, talk presented at a meeting of the Beaufort Sea Project, Victoria, B. C., 19 December 1974.

49. McMinn, T. J. and J. H. Getman, "The Coast Guard's Arctic Pollution Response Program," *OCEAN IND.*, 9 February 1974.

50. U. S. Department of Agriculture, *SNOW AVALANCHES. A HANDBOOK FOR FORECASTING AND CONTROL MEASURES*, Forest Service, Agriculture Handbook Nr 194, 1961.

51. Nobles, L. H., *SLUSH AVALANCHES IN NORTHERN GREENLAND AND THE CLASSIFICATION OF RAPID MASS MOVEMENTS*, Int. Symp. On Scientific Aspects Of Snow And Ice Avalances, Davos Switz. Publ. No. 69, Int. Assoc. Scientific Hydrol., 1965.

52. Lassiter, J. B., R. J. Powers and J. W. Devanney, *THE ROLE OF MASS TRANSPORT IN OIL SLICK WEATHERING IN PRIMARY, PHYSICAL IMPACTS OF OFFSHORE PETROLEUM DEVELOPMENTS*, Council On Environmental Quality, Report No. MITSG 74-20, April 1974.

53. Anon., *REPORT OF THE TASK FORCE--OPERATION OIL (CLEANUP OF THE ARROW OIL SPILL IN CHEDABUCTO BAY)*, vol. II, 1970.

54. Blumer, M., "Scientific Aspects Of The Oil Spill Problem," *ENVIRONMENTAL AFFAIRS*, 1, 1972.

55. Koons, C. B., *CHEMICAL COMPOSITION: A CONTROL ON THE PHYSICAL AND CHEMICAL PROCESSES ACTING ON PETROLEUM IN THE MARINE ENVIRONMENT*, working paper for Ocean Affairs Board Workshop On Inputs, Fates, and Effects Of Petroleum In The Marine Environment, May 21 thru 25, 1973.

56. Hoult, D. P., *THE AGING OF OIL SPILLED IN THE ARCTIC*, presented at the 64th Annual Meeting Of Amer. Int. Of Chem. Engr., paper No. 15C, November 28 thru December 2, 1971.

57. Smith, C. L. and W. G. MacIntyre, "Initial Aging Of Fuel Oil Films On Sea Water," *PROC. JOINT CONF. ON PREVENTION AND CONTROL OF OIL SPILLS, AMER. PETROL. INST.*, June 1971.

58. Sivadier, H. O. and P. G. Mikolaj, *MEASUREMENT OF EVAPORATION RATES FROM OIL SLICKS ON THE OPEN SEA*, American Petroleum Institute, March 13 thru 15, 1973.

59. "Prudhoe Bay Data," *OIL AND GAS JOURNAL*, 24 May 1971.

60. "North Slope Oils," *OIL AND GAS JOURNAL*, 17 May 1971.

61. H.O.R.C. Crude Assay, No. 1429, Sadlerochit/Sag River Well No. 1, November 1969.

62. Kinney, P. J., D. K. Button, and D. M. Schell, "Kinetics Of Dissipation And Biodegradation Of Crude Oil In Alaska's Cook Inlet," *PROCEEDINGS JOINT CONF. ON PREVENTION AND CONTROL OF OIL SPILLS*, API, December 1969.

63. McAuliffe, C., "Solubility In Water Of Paraffin, Cycloparaffin, Olefin, Acetylene, Cyclo-olefin And Aromatic Hydrocarbons," paper presented at Divn. Petroleum Chemistry, ACS Meeting, August 30 thru September 4, 1964, *J. PHYS. CHEM.*, 70, 1966.

64. Zarella, W. M., R. J. Mousseau, N. D. Coggeshall, M. S. Norris, and G. J. Schrayer, *ANALYSIS AND INTERPRETATION OF HYDROCARBONS IN SUBSURFACE BRINES*, paper presented at Divn. Petroleum Chemistry, ACS Meeting, March 31 thru April 5, 1963.

65. McAuliffe, C., "Determination Of Dissolved Hydrocarbon In Subsurface Brines," *CHEMICAL GEOLOGY*, 4, 1969.

66. Boylan, D. B. and B. W. Tripp, "Determination Of Hydrocarbons In Sea Water Extracts Of Crude Oil And Crude Oil Fractions," *NATURE*, 230, 1971.

67. Frankenfeld, J. W., "Factors Governing The Fate Of Oil At Sea: Variations In The Amounts And Types Of Dissolved Or Dispensed Materials During The Weathering Process," *PROCEEDINGS JOINT CONF. ON PREVENTION AND CONTROL OF OIL SPILLS*, API, March 1973.

68. Burwood, R. and G. C. Speers, "Photo-oxidation As A Factor In The Environmental Dispersal Of Crude Oil," *ESTUARINE AND COASTAL MARINE SCIENCE*, 2, 1974.

69. Seifert, W. K. and W. G. Howell, "Interfacially Active Acids In A California Crude Oil, Isolation Of Carboxylic Acids And Phenols," *ANAL. CHEM.*, 41, 1969.

70. Berridge, S. A., M. T. Thew, and A. C. Louiston-Clarke, "The Formation And Stability Of Emulsions Of Water In Crude Petroleum And Similar Stocks," *JOURNAL OF THE INST. OF PETROLEUM*, 54, 1968.

71. Mackay, G. D., A. Y. McLean, O. J. Betancourt, and B. D. Johnson, "The Formation Of Water-In-Oil Emulsions Subsequent To An Oil Spill," *JOURN. OF THE INST. OF PETROLEUM*, 59, 1973.

72. Gebelein, C. D., *SEDIMENTATION PROCESSES INVOLVING HYDROCARBONS IN THE MARINE ENVIRONMENT*, working paper for Ocean Affairs Board Workshop On Inputs, Fates, And Effects Of Petroleum In The Marine Environment, May 21 thru 25, 1973.

73. Feldman, M. H., *SOME MECHANISMS OF WEATHERING PETROLEUM HYDROCARBONS ON MARINE WATERS: COMPETITIVE PATHWAYS TO FATE AND DISPOSITION OF PETROLEUM POLLUTION*, working paper for Ocean Affairs Board Workshop On Inputs, Fates, And Effects Of Petroleum In The Marine Environment, May 21 thru 25, 1973.

74. Whitehouse, U. G., *ADSORPTION MECHANISM: ALUMINOSILICATE ORGANIC INTERACTION IN SALINE WATERS*, A.C.S. Tom M 21 (1969-1970) to be published in Advances in Chemistry Series.

75. Ludwig, H. F. and R. Carter, "Analytical Characteristics Of Oil Tar Materials On Southern California Beaches," *JOURN. WATER POLL. CONTROL FED.*, 33, 1961.

76. Guard, H. E. and A. B. Cobet, "The Fate Of A Bunker Fuel In Beach Sand," *PROCEEDINGS OF JOINT CONFERENCE ON PREVENTION AND CONTROL OF OIL SPILLS*, API, 1973.

77. Gebelein, C. D., *SEDIMENTOLOGY AND ECOLOGY OF A CARBONATE FACIES MOSAIC*, PhD Thesis, Brown University, 1971.

78. Blumer, M. and J. Sass, "Oil Pollution: Persistence And Degradation Of Spilled Fuel Oil," *SCIENCE*, 176, 1972.

79. Baker, J. M., *OIL AND SALT-MARSH SOIL*, in: "Ecological Effects Of Oil Pollution On Littoral Communities, ed Cowell Inst. Petroleum," 1971.

80. Rashid, M. A., "Degradation Of Bunker C Oil Under Different Coastal Environments Of Chedabucto Bay, Nova Scotia," *ESTUARINE AND COASTAL MARINE SCIENCE*, 2, 1974.

81. Ahearn, D. G. and S. P. Meyers, eds., *THE MICROBIAL DEGRADATION OF OIL POLLUTANTS*, Center For Wetland Resources, Louisiana State University, LSU-SG-73-01, 1973.

82. Moulder, D. S. and A. Varley, *A BIBLIOGRAPHY OF MARINE AND ESTUARINE OIL POLLUTION*, The Laboratory Of The Marine Biological Association Of The United Kingdom Plymouth, 1971.

83. Zobell, C. E. and J. Agosti, *BACTERIAL OXIDATION OF MINERAL OIL AT SUB-ZERO CELCIUS*, Abstracts, Am. Mtg. Amer. Soc. Microbiol., P. 2., 1972.

84. Zobell, C. E., *BACTERIAL DEGRADATION OF MINERAL OILS AT LOW TEMPERATURES*, in: "The Microbial Degradation Of Oil Pollutants," ed. Ahearn, D. G. and S. P. Meyers, Center For Wetland Resources, Louisiana State University, LSU-SG-73-01, 1973.

85. Robertson, B., S. Arhelger, P. J. Kinney, and D. K. Button, *HYDROCARBON BIODEGRADATION IN ALASKAN WATERS*, Center For Wetland Resources, Louisiana State University, LSU-SG-73-01, 1973.

86. Atlas, R. M. and G. R. Bartha, "Biodegradation Of Petroleum At Low Temperatures," *COUN. J. MICROBIOL.*, 18, 1972.

87. Button, D. K., *ARCTIC OIL BIODEGRADATION*, Office of Research and Development, USCG, Report No. CG-D-114-75, October 1974.

88. Traxler, R. W., *BACTERIAL DEGRADATION OF PETROLEUM MATERIALS IN LOW TEMPERATURE MARINE ENVIRONMENTS*, Center For Wetland Resources, Louisiana State University, LSU-SG-73-01, 1973.

89. Gunkel, W., *SOME REFLECTIONS ON THE BIODEGRADATION OF MINERALS OILS IN THE MARINE ENVIRONMENT*, working paper for Ocean Affairs Board Workshop On Inputs, Fates, and Effects Of Petroleum In The Marine Environment, May 21 thru 25, 1973.

90. Cook, F. D. and D. W. S. Westlake, *MICROBIAL DEGRADATION OF NORTHERN CRUDE OILS*, Environmental-Social Committee Northern Pipelines Task Force On Northern Oil Development, Report No. 74-1, April 1974.

91. Parkinson, D., *OIL SPILLAGE ON MICROORGANISMS IN NORTHREN CANADIAN SOILS*, Environmental-Social Committee Northern Pipelines Task Force On Northern Oil Development, October 1973.

92. Atlas, R. M. and R. Barther, "Degradation Of Mineralization Of Petroleum In Sea Water: Limitation By Nitrogen And Phosphorus," *BIOTECHN. BIOENG.*, 14, 1972.

93. Reisfield, A., E. Rosenberg, and D. Gutnick, "Microbial Degradation Of Crude Oil: Factors Affecting The Dispersion In Sea Water By Mixed And Pure Cultures," *APPL. MICROBIOL*, 24, 1972.

94. The Alaskan Arctic Coast, Alaska District, Corps of Engineers, Anchorage, Alaska, June 1974.

SECTION 6. OIL SPILL CONTAINMENT AND CLEANUP: A REVIEW OF METHODS AND EFFECTS

Whether an oil spill occurs in the open water, on ice, or on land, response is required in three principal operational modes: (1) securing or minimization of the oil reservoir of the spill source, (2) containment of the spilled oil, and (3) removal or dispersion of spilled oil. This study does not encompass a review and evaluation of techniques for securing the source of the spill, such as a distressed tanker, ruptured pipeline, or platform blowout. For the purposes of this study, fixed volumes of spill were specified, thus only containment and cleanup methods and their potential effects were reviewed. Extensive studies of various aspects of containment, cleanup, and dispersion have been funded by the Coast Guard, Environmental Protection Agency (EPA), and the American Petroleum Institute; the resulting comprehensive reports will be noted in the bibliography for the appropriate topic. Cleanup and containment activity will differ for open-water spills and ice or land-bound spills and the state-of-the-art for each situation will be discussed separately.

A. CONTAINMENT OF OIL SPILLS ON OPEN WATER

The principal means of containing oil spills on open water are floating mechanical barriers (oil booms), air bubble barriers, and chemical barriers (surface tension modifiers). Some curtailment of the spread of oil or redirection of the spreading may also be affected by the use of water jets.

(1) FLOATING BOOMS OR BARRIERS

A comprehensive review of oil containment systems was published by the Oil Spills Branch of the EPA in October 1970 and updated in January 1973. The salient features influencing boom effectiveness are discussed in a publication of the Office of Water Program of the EPA.[2] Eighty-five specific boom designs were described by Sittig,[3] who compiled the information available from the U.S. Patent Office as well as the data published in References 1 and 4--the second a state-of-the-art review by the National Maritime Research Center.

Although there are many designs, floating oil containment booms have the following basic functional components: (1) flotation or buoyancy components, (2) weighting components to achieve desired boom orientation in the water, (3) submerged skirt to restrict oil flow under the boom, (4) freeboard or surface barrier to minimize surface escapement, and (5) longitudinal force carrying components to provide structural integrity to the boom under severe wind, wave, current, and handling stresses. Booms may be classed as flexible, semiflexible, and rigid according to the ease and degree to which the boom follows wave action. Rigid booms (rigid sections or modules joined by some form of hinges) predominate in the current state-of-the-art due to their overall strength, durability, and stability properties. In any boom design, consideration must be given to the ease of handling (storage, assembly, transport, and deployment) as well as the functional aspects of containment effectiveness and durability. In addition to commercially available booms, many improvisations have been used in past spill incidents with varying degrees of success. Most common improvisations utilize timber, whether telephone poles, railroad ties, or trees cut on site, linked together in some fashion to provide continuity. Since such improvised booms have limited freeboard and effective "skirt" depth, as well as substantial mass, successful use has been largely restricted to quiet, protected waters with very low currents. The limits imposed by currents, wave action and wind also dictate the utility of commercial booms, since all booms work best in calm, non-moving water.

In any given spill situation, booms may be used in several ways. If currents and sea state are low, booms may be towed in the characteristic U-shape by workboats to help collect the oil in thicker layers for increased efficiency of removal devices. Towing speeds must in general be such that the net water velocity perpendicular to the center elements of the boom is less than 1 knot* to minimize oil escapement. In situations where currents of 1 knot or higher exist, due to combined wind and tidal action, the boom may be held stationary to allow the oil to drift in, or the boom may be allowed to drift with the effective current at some fraction of the current velocity to maximize oil retention. Other operations scenarios may involve the use of the boom as an oil-deflection tool to either direct oil toward removal equipment or to protect sensitive areas.

Regardless of specific design solutions, booms may in general be classified as high-seas or offshore booms and "calm water" booms. This discussion concentrates on high-seas booms since, for the most part, the

*The commonly quoted figure for effective containment is 1.2 ft/sec or 0.7 knot; 1 knot for small escapement allowed is used herein.

environmental conditions to be expected in Alaskan waters will be of the "high seas" type with significant wave, current, and wind action. High seas booms are characterized by their sea-keeping ability, rugged construction, and deep effective draft.

The effectiveness of any given barrier is governed by its sea-keeping characteristics (motion of the barrier in waves) and the current field at any particular element or module of the boom. As noted above, the effective current field may be determined by tidal and/or wind induced currents, towing or motion of the barrier in the waves. Consider first the behavior of an oil slick ahead of a (typical) boom as shown in Figure 6-1 for calm water. As oil collects in front of a boom, a headwave of oil forms some distrance upstream from the boom. Containment is effective with only slight oil loss until the resultant current exceeds approximately 1 knot at which time oil droplets are generated at the headwave and swept back. Some of these may rejoin the slick inside the boom and some are beginning to be swept under the skirt (approximately 50-50 according to Ref. 5). As the current increases to roughly 1.5 knots, the oil lost increases by a factor of 10. The upper limit of any useful containment at all for the majority, if not all, booms to date is 3 knots with 2 knots a more realistic figure. The low speed (< 1 knot) retention of a boom may be improved by extending the subsurface skirt or inclining it forward via use of bottom tension towing (Ref. 6).

Rough water conditions introduce other considerations in the evaluation of boom effectiveness. Foremost of these are the sea-keeping characteristics of the boom. An effective barrier must heave up and down in synchronism with the waves in order to mimimize freeboard height and skirt depth variations, i.e., that oil not pass over or under the barrier. For the same

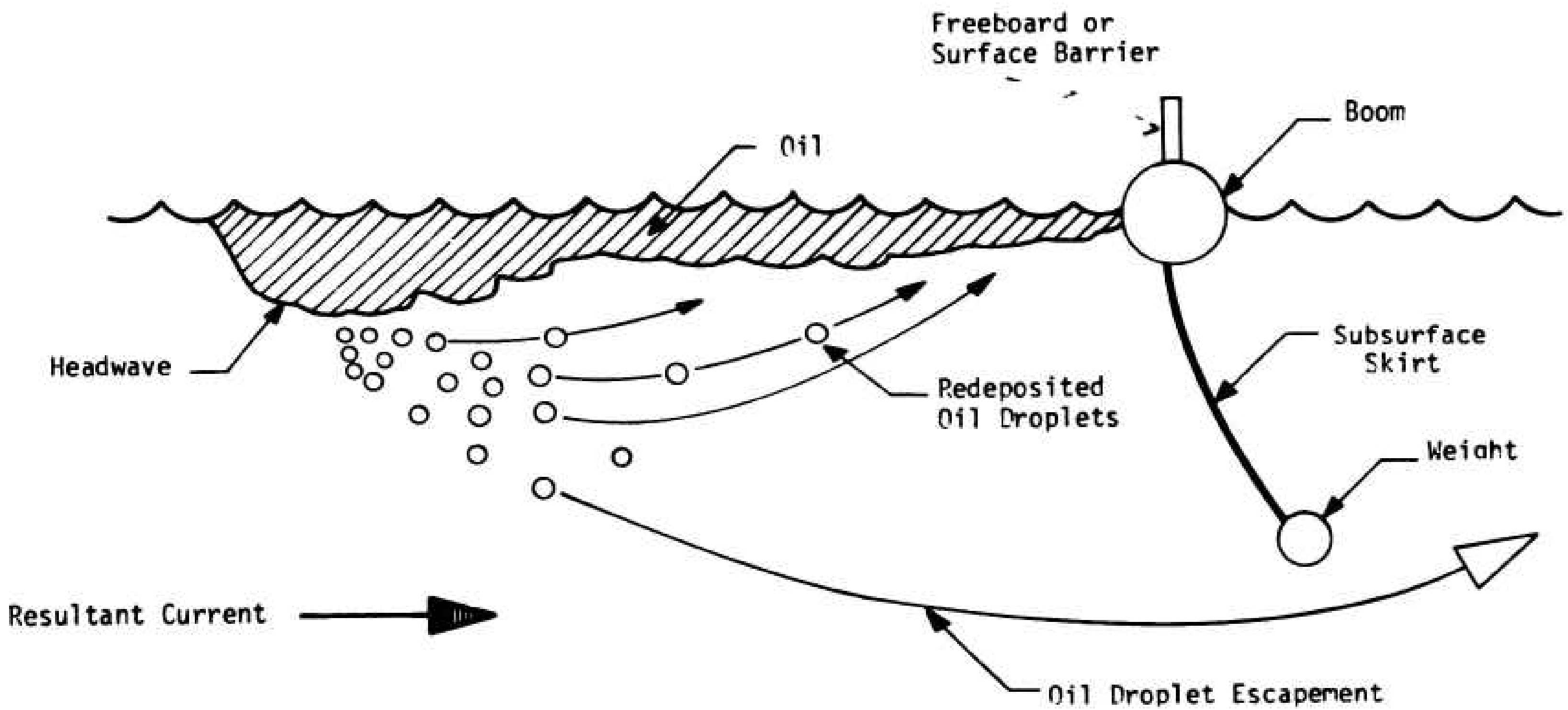


FIGURE 6-1. BEHAVIOR OF AN OIL SLICK IN CALM WATER

reasons, the roll angle of individual modules must remain small. The sway response of a barrier will determine the oil retention characteristics by how the sway motion affects the current field, c.f. (Fig. 6-2). Sway response of a barrier should be designed so as to minimize the currents relative to the barrier while not decreasing the effective depth to where escapement occurs. Another mechanism that increases loss of oil under the boom is the added current at the oil headwave due to the orbital velocity in the swell or wave; this mechanism may also prevent detached droplets (Fig. 6-1) from rejoining the slick ahead of the boom. Unless the freeboard is sufficiently high and heave motion is synchronized, breaking waves in short-crested seas may carry oil over the top of the barrier.

The above failure mechanisms for booms are fairly well understood and are characteristic of almost all booms available today. A more detailed discussion of the failure mechanisms and strength design requirements was given by Milgram,[7,8] Chung, et al.,[9] Wicks,[10] Glaeser,[11] and Abrahams.[5] Other design concepts involving streamlined booms and booms incorporating weir devices[12] have been proposed; however, these have not been subjected to full-scale testing under realistic high seas conditions, and no conclusions concerning potential improvement over existing booms may be drawn at this time. It is important to note that the severe loads under which high seas booms must operate dictate simplicity in design; all booms in use today suffer a high damage and loss rate[13] except under very mild conditions.

An extensive research effort has been undertaken by Rensselaer Polytechnic Institute (RPI) under contract for USCG (DOT-CG-33, 755-A) to

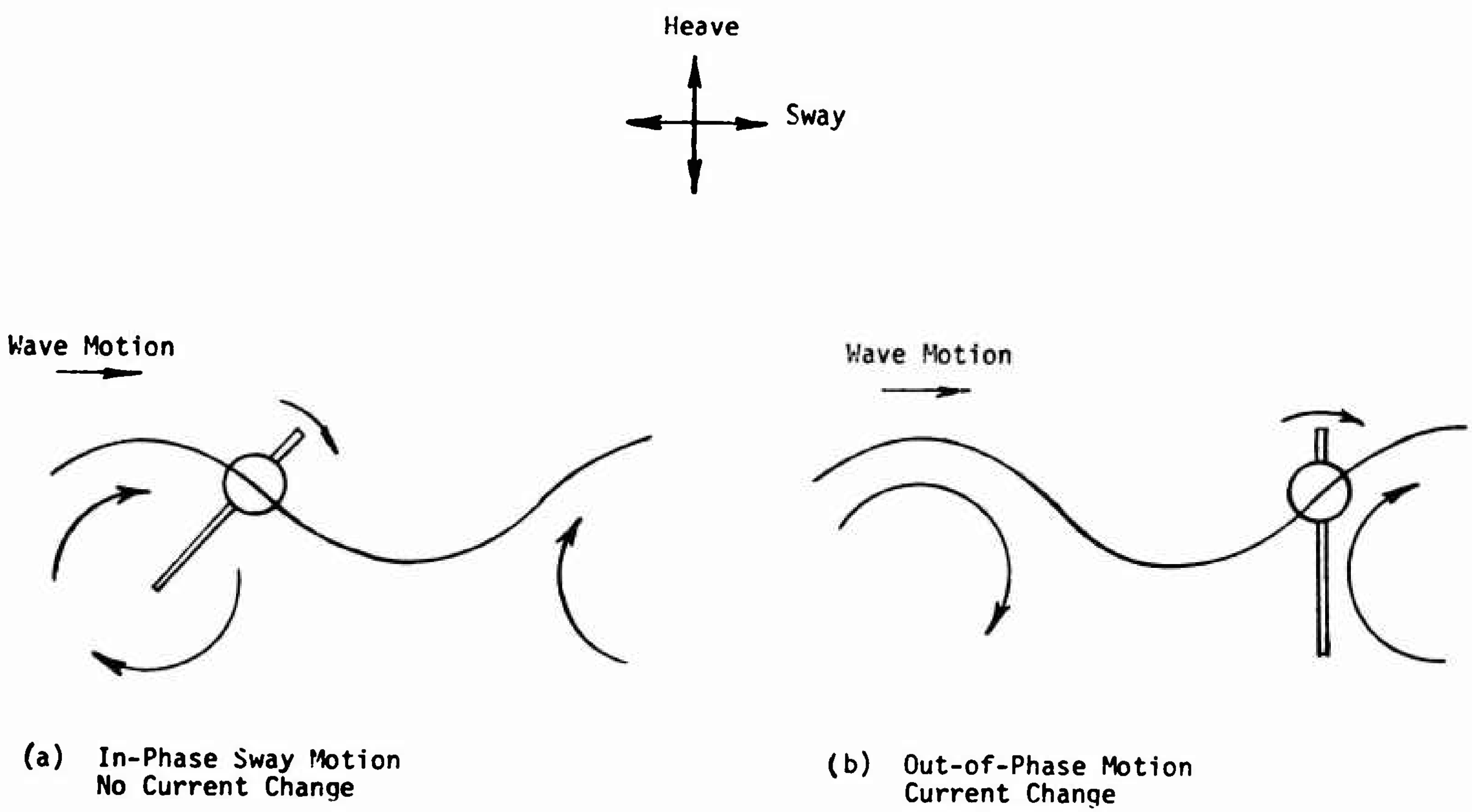


FIGURE 6-2. SWAY RESPONSE OF BOOM IN WAVES

evaluate the state-of-the-art of using chemical additives to improve the control of oil spills at increased current velocities up to 10 knots. The interim report by RPI[14] contains an exhaustive bibliography on the subjects of oil slick behavior, oil spill containment, and removal and modification of oil properties by additives. A detailed discussion of the various mechanisms available for reduction of oil loss under barriers is presented in Reference 14 as well as evaluation of each specific mechanism, such as reduction of oil/water interfacial drag, oil slick gellation, increase in oil/water interfacial stability, and promotion of oil droplet slick coalescence.

(2) AIR BARRIERS

Air or bubble barriers consist of submerged perforated pipe or tubing from which compressed air is released. The resultant rising curtain of bubbles produces an upswelling on the water surface above the tube and a horizontal surface current away from the mound. Air barriers will not contain oil in currents as low as 0.4 knot, and this effectiveness is further degraded by the orbital velocity induced by wave action. In Figure 6-3, the circulation patterns of an air bubble barrier in quiet waters and the effects of current are illustrated. In still waters, the maximum surface current, Vm, created by an air barrier, is related to the volume flow rate of air per unit length of manifold Q by

$$Vm = k(gQ)^{1/3}$$

where k is a constant and g the acceleration of gravity. The surface current reaches a maximum at a distance L from the manifold and then decreases

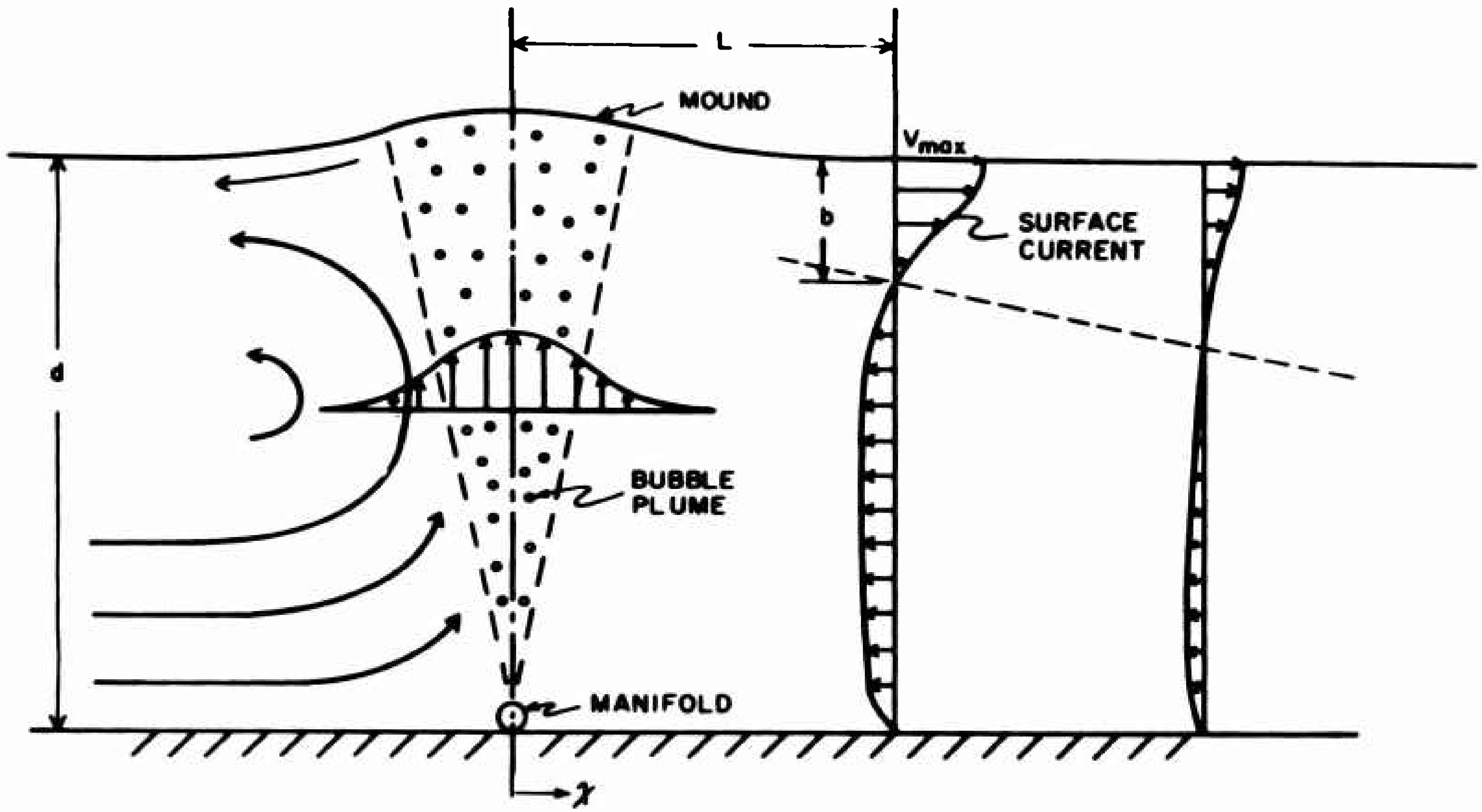


FIGURE 6-3. CIRCULATION PATTERN AND VELOCITY PROFILES IN AIR BARRIER

approximately proportional to $1/\sqrt{x}$ where x is the distance from the manifold. The distance L is found to vary from d, the depth, to d/z. The depth of the surface current, b, is about d/4 at x = L and increases linearily for larger x. When currents are superposed (Figure 6-4), the plume bends over; if the plume deflects over 30^{o} from vertical, the plume breaks up. Oil loss through a bubble barrier results from turbulent entrainment of oil particles in the water which may be passed through the plume.

In general, air on bubble barriers requires large amounts of power and specialized equipment. Due to loss of effectiveness with current and waves, these barriers are useful primarily in sheltered harbor areas and, hence, of limited utility in potential Alaskan spill situations studied in this report.

(3) CHEMICAL BARRIERS

Certain surface-active chemicals, which alter the balance of interfacial tension forces at the junction of the air-water, air-oil, and oil-water interfaces, may be used to contain the spreading of oil slicks. The study of surface-active chemicals (oil herders, piston films, etc.) in the laboratory and field has shown that such chemicals can aid in containing oil. Barger[15] reported on an evaluation of 47 surface-active chemicals; however, the field conditions assumed water temperatures of greater than $5^{o}C$. The effects of water at $0^{o}C$ on the chemicals and their action are currently unknown. Details of the known characteristics of surface films are given in Garrett and Barger.[16] As is the case with air barriers, chemical agents of this type have been shown to be useful in quiet waters and smooth swells; choppy and breaking seas will impair effectiveness. Since the

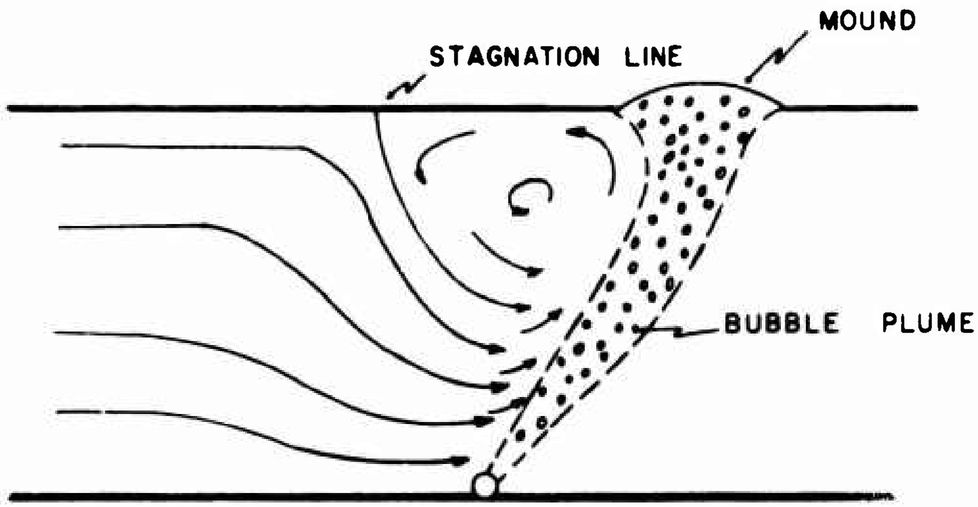


FIGURE 6-4. CIRCULATION PATTERN UPSTREAM OF AN AIR BARRIER IN A CURRENT

surface film will drift along with the oil, currents may not be detrimental to the action of the chemicals. However, since spreading occurs in all directions from the point of application, away from the oil slick as well as toward, periodic reapplication may be necessary or concurrent use of mechanical barriers, etc., may be dictated. The effects of a given application will last for a few hours at the most, so immediate cleanup activity is necessary in conjunction with use of these materials.

B. OIL REMOVAL FROM OPEN WATER

Oil removal from an open water surface involves some type of skimming device. Skimmers may operate directly on the oil slick on the water or on oil-saturated sorbent material that has been broadcast on the slick. The design requirements for these two functional modes of operation are quite different and will be discussed separately. Direct oil skimmers may be classified according to the method by which oil is removed from the water surface. To date, oil removal devices based on weir action, suction, sorbent, vortex, screw, conveyor, and jet action have been proposed in the literature, and many operational units exist. Primary design requirements for skimmers are (1) ease of handling, (2) ease of operation, (3) low maintenance (high reliability), (4) strength and durability, (5) versatility of operation under various current and wave conditions, (6) high oil recovery rate, and (7) ease of transportation to remote areas. Requirement (7) may translate into air-drop capability for most anticipated USCG operations in Alaska. Present day skimmers are designed to one or more of the above requirements, none exist which meet all satisfactorily.

For the most part, environmental factors such as currents, wave action, and floating debris limit the capacities of skimmers; wave limitations of less than 2 ft (0.6 m) and current limitations of less than 1 knot would preclude the use of most present-day designs in typical Alaskan conditions. Most of the readily transportable commercial devices available today would pose danger to the operating personnel at the majority of the sites studied in this report. From both functional and safety points of view, use in most spill situations would be restricted to protected embayments and inlets. The other major factor to consider in any skimmer design is the minimum operating depth of the device as well as the degree of hull bottom, propulsion system, and operational mechanism protection. Since most cleanup operations can be expected to take place in (relatively) uncharted waters, immunity to underwater hazards is highly desirable.

As noted above, when wave heights approach 2 ft (0.6m) and currents exceed 2 knots, direct skimming of oil becomes either impossible or highly inefficient due to the high water-to-oil ratio. Under these conditions, removal with the aid of sorbent materials and suitable sorbent harvesting vessels is necessary. When considering sorbent-aided oil recovery, the entire sorbent system must be considered, involving such factors as sorbent supply, whether stored or generated *in situ*, sorbent broadcasting, oil-sorbent harvesting, oil-sorbent separation, storage and/or disposal. Sorbent characteristics will be discussed separately in this report; insofar as properties of the recovery system are concerned, the major considerations are sea-keeping ability of the vessel, durability of the recovery mechanism under severe sea conditions, susceptibility to floating debris, and the (safe) operating depth of the vessel.

The principal features of both direct oil recovery and sorbent harvesting devices will now be briefly described. Devices are classified according to the principal recovery mechanism of the device: weir, suction, drums, belt or disc, vortex, screw, or jet recovery. Figure 6-5 illustrates the key features of these recovery mechanisms. Detailed information on various devices is given in Sittig[3] and by EPA.[17]

(1) WEIR DEVICES

Weir devices depend on gravity to drain oil off the surface of the water (Fig. 6-5a). The oil is allowed to overflow the weir into a collecting device from which it may be pumped; to improve efficiency (decrease water pickup), weirs may be staged. The weir, itself, may take many configurations (smooth plate, saw-tooth, etc.) and is either integrated with the skimming vessel or forms an attached subsystem. Various tests of simple weir skimmers have shown that these devices perform poorly in any but calm waters due to increasing recovered water/oil ratio. Some improvement under smooth wave conditions may be expected by allowing weir movement in synchronism with wave action. Several mechanisms (illustrated in Fig. 6-6) have been proposed to increase the recovered oil fraction such as the hydro-adjustable saucer weir (6-6a), simple saucer weir (6-6b), vortex weir (6-6c), multiple-cascade weirs (6-6d), and multiple-cascade coupled with dynamic head weirs.

(2) SUCTION DEVICES

Floating suction devices (Fig. 6-5b) will operate under about the same environmental conditions as weir devices but exhibit a higher failure rate due to debris clogging of the floating suction head. Usually for these

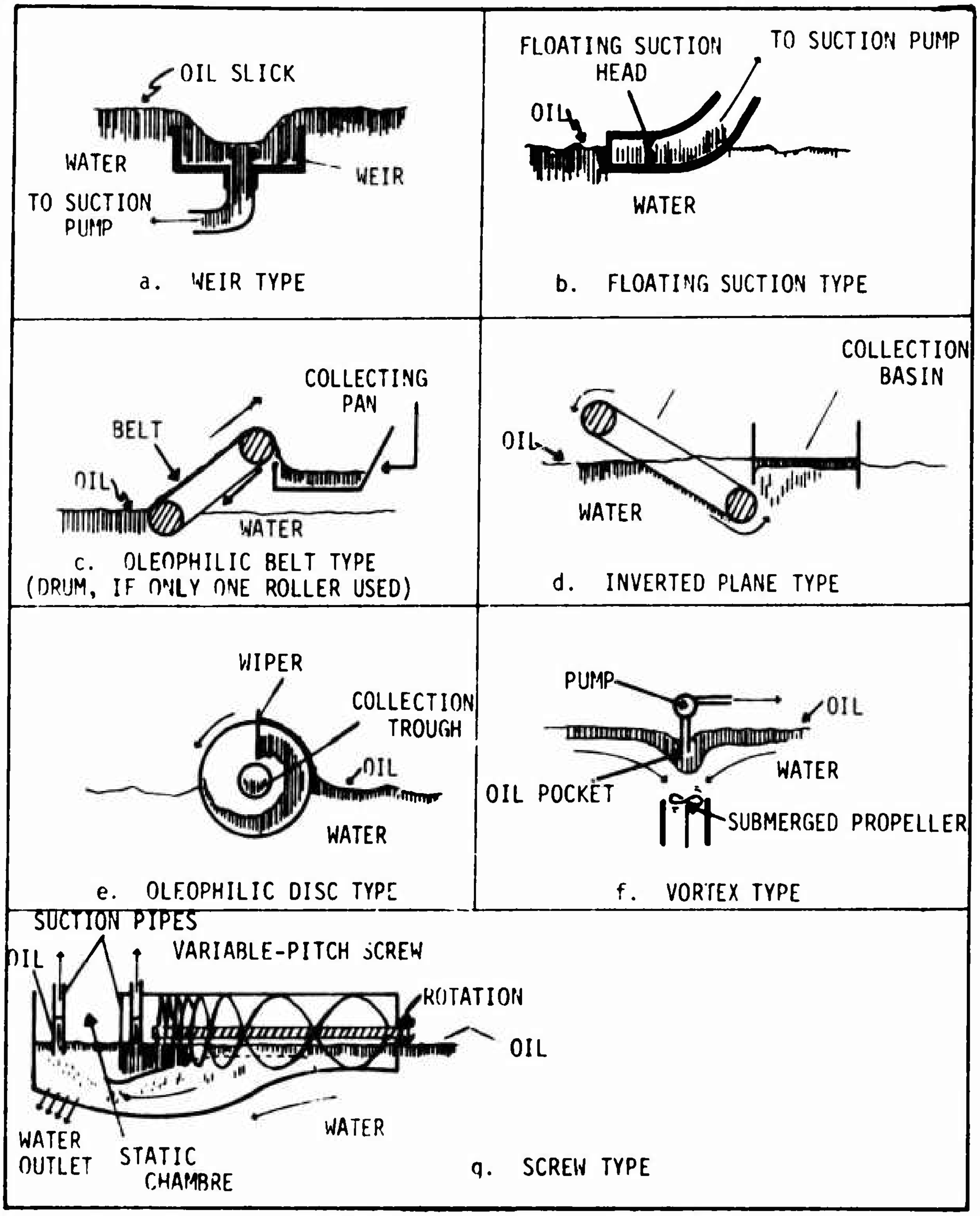


FIGURE 6-5. CLEANUP DEVICE TYPES

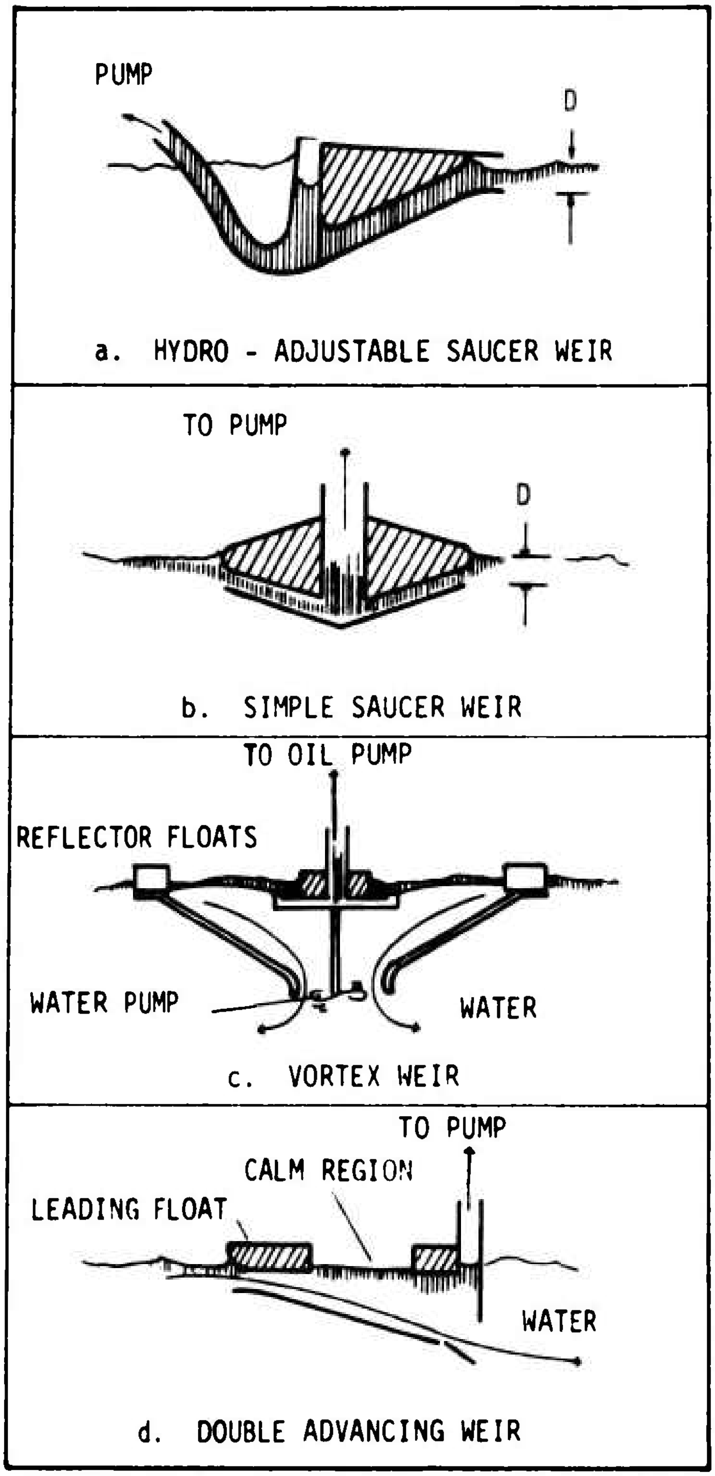


FIGURE 6-6. WEIR TYPE VARIATIONS

types of devices, the suction head is a separate subsystem of the support vessel and, because of the shallow draft, may be effective for removal of oil from shallow water areas. Past operational experience indicates that these devices are useful primarily in protected harbor areas.

(3) DRUM, BELT OR DISC DEVICES

(a) OLEOPHILIC BELTS, DRUMS AND DISCS

Among the most effective of skimming devices tested under field conditions have proved to be the oleophilic belt or disc (Figs. 6-5c and 6-5e) devices. This type of device, employing a disc, belt or drum with a sorbent surface is somewhat less susceptible to wave and current action. However, the efficiency of recovery will depend on oil thickness, degree of oil weathering,affinity of the sorbent surface for oil, cycling rate of the disc, belt or drum and the velocity of the skimming vessel. With drum type devices, significant wave action may reduce the amount of oil recovered since the oil film layer contacts the drum at varying rates reducing pick-up efficiency. The same type of problem exists for the belt devices. Operation can be improved in smooth waves by making the pick-up device follow the wave action; however, this usually occurs at the cost of losing structural durability.

(b) INVERTED BELTS

Another class of devices utilizes the inverted endless belt concept, (Fig. 6-5d). Operational experience with a unit of this type[18] indicated that many of the shortcomings of oleophilic belts, drums and discs can be overcome in this concept. Particularly useful is the ability to cope with oil of all stages of weathering as well as oil-soaked debris that will be encountered in any spill situation. Successful skimming in 3 to 4-ft choppy seas indicated that these devices hold promise for operation with expected Alaskan conditions. Because of the ability to harvest free slicks as well as oil-soaked debris, the inverted belt skimmers can also be used to recover sorbent/oil mixtures. At the present time, considerable development work is still necessary to increase the capacity of the vessels, improve sea-keeping characteristics of the belt mechanisms to follow wave action and recycle sorbents, if used in a sorbent-aided cleanup system.

(c) CONVEYOR BELT

Conveyor belt concepts for recovering sorbent/oil mixtures have been explored by various companies; typical results of these studies are reported by contractors to EPA under research contracts to develop sorbent systems for oil spill cleanup.[19] All contractors selected open mesh wire belting mounted on standard conveyors, with or without flights to aid sorbent retention for high conveyor inclination angles. Because of the difficulties experienced by belt and drum type skimmers due to severe wave action, this concept does not appear as good as the inverted belt concept for rough sea operations. Also, high winds may cause problems for the exposed conveyor belts. However, the standard conveyor systems may be mounted on vessels of opportunity whereas the inverted belt mechanisms require, at this stage of development, specially designed skimming vessels.

(4) OTHER DEVICES

Devices based on other principles from those discussed thus far have been proposed in the literature, and some have been tested either in model or prototype form. Examples of such devices are the variable pitch screw[20] (Fig. 6-5g) which can be incorporated in different skimming vehicles, free-vortex collection devices,[21] and double weir-basin skimmers[22] (Fig. 6-6d). The double weir-basin recovery system is one of two concepts for high seas oil recovery under development for the USCG (the other concept is a drum-disc device[23,24]).

Because of the likelihood of sorbent use as well as high probability of contaminated debris under most of the postulated spill conditions, combined with the logistics problem, it is felt that the screw-based concepts will not be of high utility in the near future. Free-vortex collection devices and surface suction pumps are susceptible to debris clogging; hence, in general they would be of limited use in ice-infested waters or highly debris-laden waters. However, small units of either type that may be operated as hand-held skimmers would prove useful for recovery of oil floating in ice-free pools or small shallow water areas near shore where mechanized skimmers cannot operate. The need for such small, mobile units has been identified by various oil cleanup cooperatives and a prototype hand vacuum cleaner-style skimmer system has been developed under the auspices of Clean Bay Associates, the oil cleanup cooperative for the Gulf of Mexico.

C. CONTAINMENT AND CLEANUP IN ICE-INFESTED WATERS

If a spill should occur in ice-infested waters, the effectiveness of the majority of containment and cleanup devices discussed herein is greatly modified. The fundamental characteristic of such spills is the incidence of moving solid ice chunks, ranging in size from small (order of inches) pieces to substantial blocks (order of feet). Under such conditions, conventional containment barriers deployed in a containment mode will fail by rotating up and onto the ice. If these barriers are relatively "smooth" so as not to allow ice to sway on the barrier during relative along-the-boom motion or abrade the barrier, then they still may be useful in a deflection mode, for example, used to deflect clean flowing broken ice away from contaminated areas. The Coast Guard-developed High Seas Oil Containment Barrier, utilizing an external tension line, does not exhibit the failure mode of conventional barriers as demonstrated during USCG tests off Homer, Alaska, in November and December of 1973.[43] However, any boom with external tensioning, because it does not allow ice load relief by riding up onto the ice, will eventually be subject to structural failure and/or mooring system failure if used in a strictly containment mode.

Because of the new dynamic phenomena introduced by the movement of ice chunks and/or floes, new tactics for containment and cleanup will need to be developed in addition to necessary modifications of equipment. Such new developments should result from ongoing U. S. Coast Guard programs of testing and evaluating spill response equipment under Arctic conditions.

D. THE USE OF SORBENTS ON WATER

The efficiency of containment and cleanup of oil spills on water is usually improved by the use of sorbent materials to restrict oil spreading and to act as preliminary pickup devices to be subsequently harvested. As reported by McMinn,[25], the use of sorbents is of limited utility under Arctic conditions due to mixing requirements and the increased viscosity of the spilled oil. In the more temperate areas, it is expected that sorbents will be useful if effective harvesting techniques are available.

Although many products,[26] both natural and artificial, have been proposed for use as oil sorbent agents, certain operational restrictions dictate what could actually be used in postulated Alaskan spill situations. The primary requirements are going to be related to the logistics of supply, application, and subsequent harvesting. The general properties of sorbents are compactly reviewed in Reference 2. The general concensus at this time is that in-situ generation of synthetic foam--high tensile strength, industrial polyurethane foam--would be most preferable, with the current state-of-the-art dictating storing pre-manufactured, pre-packaged (in compressed form for ease of storage, handling, and transport) foam at selected locations. At this time, insufficient information exists about the probable logistics of USCG spill response in Alaskan waters to recommend specific storage locations. Based on Battelle's analysis[27] of current logistics, one could select nominal locations; however, the calculated response times from these locations, for the most part, limit the effective use of sorbents. The pre-packaged sorbents should probably have air drop capability for most expected response scenarios.

With regard to the use of sorbents, it is noted that use on water should only be initiated if harvesting is possible, and it can be assumed that almost all sorbents can be recovered during any given cleanup operation. Since oil locked in a sorbent cannot disperse due to natural mechanisms, and biodegradation beyond the surface layers is also limited, the impact of non-recovered oiled sorbent may be larger than the free oil if weather conditions interrupt harvesting operations and the sorbent becomes widely scattered. Finally, one notes that increased viscosity, as a result of weathering and low temperature, will substantially decrease the effectiveness of the majority of sorbent materials.

E. PHYSICAL-CHEMICAL TREATMENT OF OIL SPILLS ON WATER

In addition to physical containment and mechanical and/or manual pick-up of oil spilled on open water, other methods such as dispersion, sinking, gelling, or coagulation and combustion have been proposed.

(1) DISPERSION

Dispersion of oil in the water column can be accomplished either mechanically or chemically. Mechanical dispersion activity, as a result of agitation of the oil with high-pressure water jets, mixing action of boat propellers, etc., usually accomplishes precisely the opposite of the desired effect. Instead of small oil droplets dispersing through the water column, highly stable water-in-oil emulsions are formed which persist for long periods of time. Such emulsions also result from natural wave action (c.f., Section 5-E-c) during storms. As a consequence, mechanical dispersion activity should normally be avoided.

The use of chemicals to disperse oil slicks has been under study for many years and the controversy regarding the merits and shortcomings of chemically dispersing oil spills is far from resolved. Dispersants can, in general, be classed as self-mixing (requiring no external mixing energy) and "conventional" (requiring input of mixing energy after the dispersant has been applied to the oil slick). Because of operational restrictions, conventional dispersants will, in all likelihood, be of limited utility for Alaskan spills; therefore, their characteristics are not reviewed herein.

Self-mixing dispersants do present potential utility and, hence, MSNW reviewed the state-of-the-art here. Canevari[28,30] extensively reviewed the utility of self-mixing dispersants as well as elaborated on the mechanisms of dispersion involved.

Self-mixing dispersants form uniform sub-micron diameter oil droplets through surfactant diffusion into the water column. As the surfactant components of a self-mix dispersant formulation diffuse into the water column, small droplets of oil associate with the surfactant resulting in effective dispersion through some 2 to 5 m of the water column because of the diffusion mechanisms. Subsequent vertical dispersion occurs due to orbital water movement associated with waves and any shear currents that may exist in a region. Because of the extremely small size of the dispersed oil, resurfacing is unlikely -- Canevari noted that the sub-micron droplets exhibit Brownian motion.

The absence of mechanical mixing requirements and improved effectiveness of the self-mix dispersants may allow their application through suitably developed aerial dusting techniques to large slicks in open water. Whether or not such dispersants can be used depends on the legislative restrictions governing their use in effect at the time of the spill. At the present time, conventional dispersants are routinely used in parts of the world[31] other than the U.S.; the National Contingency Plan[32] at this time specifies under what conditions dispersants may be used, subject to USCG and EPA approval, for any specific incident. The regulations governing the use of dispersants should be periodically reviewed as new information regarding effectiveness, toxicity, and eventual fate of dispersant and dispersant/oil combinations is developed.

Dispersant use is regulated to minimize the environmental impact of a given spill due to toxicity considerations. Numerous bioassay tests have been conducted on dispersant toxicity and dispersed oil toxicity. The results usually indicate (Battelle[33,34]) that oil, chemically dispersed, is toxic at lower concentrations because the dispersed oil is made more available to marine organisms. However, care must be taken in applying laboratory bioassay results to predicting impacts in the open environment. In real spills, the degree of dispersion (and consequent dilution) in the water column will depend on many physical variables (c.f., Section 5-D) and the degree of weathering. Studies of the toxicity and eventual fate of finely dispersed oil in the open environment are necessary over long periods of time in order to correctly assess whether or not self-mixing dispersants will prove to be an effective tool for combatting spills. Since other counties are using dispersants of various types extensively, such real spills should be studied to correlate laboratory results with what may be expected in the field.

(2) SINKING

Sinking agents are oil-attracting and water-repelling sorbent materials designed to sink oil particles. Existing legislation[32] prohibits the use of sinking agents on navigable waters of the U. S. Various studies both in the U.S. and abroad have investigated the utility and effectiveness of different sinking agents. Since most sinking agents have to be applied in high sinking agent weight to oil weight ratio (one-to-one or higher), the logistics of widespread use in Alaskan waters, even if permitted, would be prohibitive. Furthermore, since even less is known about the eventual fate of sunken oil and its effects on the overall biotic chain than about dispersed oil, use of sinking as a method of cleanup cannot be advocated at this time. Much more about the degradation of sunken oil still needs to be learned.

(3) GELLING OR COAGULATION

It has been proposed[35] that gellation of the headwave region of an oil slick (Fig. 6-1) may accomplish a reduction of oil entrainment losses from boom contained slicks and, hence, aid in the containment and cleanup efforts. The state-of-the-art of using gellation techniques (as well as other chemical means) to increase containment effectiveness has been reviewed by Rensselaer Polytechnic Institute[14] under contract to the USCG. Gellation of oil slicks has been discussed, but no record exists of field trials. Corino[36] discussed gellation along with dispersion, Fuller[37] considered gellation and absorption, and Dewling and Dorrier[38] considered gellation as an auxiliary to the use of "oil herders" or chemical barriers. The drawbacks to field use of gellants are the large quantities (gellant/oil ratio high) required and the mixing requirements. If the gellant/oil ratio can be significantly lowered and the toxicity reduced (most gellants available today are toxic to some degree), then gellation as a means to improve containment and cleanup efforts will become attractive.

(4) BURNING

Burning of oil on the sea has been proposed, and some field trials attempted, but this method does not appear a feasible one for Alaskan spills.

To have any chance of success, the oil must be fresh and in reasonably thick continuous slicks. In view of the anticipated response times[27] for most Alaskan spills, the evaporation processes will, in general, have removed almost all of the highly flammable components from the oil, hence burning would prove difficult even with the aid of incendiary materials and burning aids (wicking agents). For wicking agents to work, practically all the oil must be covered by the added material; the implied volume and distribution task plus subsequent ignition make the use of burning on the open water a practical impossibility. Use of burning agents in the close proximity of the oil spill source (distressed tanker, barge, platform) must not be allowed in case the flame "feeds back" to the spill source creating a larger problem both from a safety and a pollution point of view.

F. CLEANUP OF OIL SPILLS ON OR UNDER ICE

The methods that may work in cleaning up oil spills on or under ice that is, in some sense, cohesive, are limited by the increased viscosity of the oil, the logistics of supporting a cleanup effort, the problems of establishing a working base, and available disposal methods for the recovered oil. Field experience in this area is very limited; the tests of cleanup methods conducted by the USCG[25] are not really indicative of the accidental spill situation. However, at this time it appears that, for spills on the surface of the ice, manual and mechanical harvesting and burning are the only viable methods. For spills under ice, if the extent and boundaries of the sub-ice oil pool(s) are known, cutting access holes in the ice and pumping appears to be the only method available today.

Manual and mechanical cleanup operations on open-sea ice, which is continually in motion with leads opening and closing, will be determined by the availability of a vessel working platform and depend on a continual monitoring of the ice dynamics. Personal safety considerations will need to be weighed at the time and location of any specific spill.

The local stability of the ice pack,and hence its utility as a work platform, will depend on specific location and time of year. If the spill occurs either during freeze-up or break-up, then water-borne vessels will have to be used to provide a work platform. During mid-Winter, the leads formed by the ice-breaking action of either the distressed tanker or cleanup vessels will close quickly. This closure will cause ridging as the broken rubble field is compressed by pack pressure. The time required for the ridging to stabilize is not known at this time. An overriding consideration for any cleanup activity under ice conditions is a problem of disposal or storage of the recovered oil. It is unlikely that the stricken vessel would have storage space available.

From these considerations, it appears that the only feasible method of dealing with oil spills on ice is burning. Because of the decreased evaporation rate in the Arctic, more volatiles will be retained in the slick and because of the temperatures involved (plus surface roughness effects), the oil will lie in fairly thick pools. These factors would enhance burning of the oil. For spills under ice, one would "drill for oil" and pump as much as possible onto the ice surface for subsequent burning.

Although burning appears to be the only feasible means of combating an oil spill on or under ice at this time, a note of caution is in order. In Section 5-C-2-a, the possible long-term interaction of oil and the ice pack was discussed and the potential adverse effects of dispersed oil on the albedo of the pack noted. Changing of the albedo interferes with the current equilibrium melt and growth cycle of the pack and, due to pack motion, this effect is probably widely distributed in the Arctic. It is well known that any burning of oil, particularly crudes and heavy fuel oils, results in extremely heavy smoke. At this time it is not known what the particulate composition of the smoke is, both in number and particle size distribution. Furthermore, it is not known what percentage (by weight or volume) of the original oil will be distributed in the smoke and left as residue. We note that both the residue and smoke particles, which will be distributed over a very large surface area at substantial distances away from the actual spill site, can be effective in changing the albedo of the pack. The distribution of the smoke particles by the winds is an effective means of (potentially) altering the surface albedo of large areas, particularly if large volumes of oil are burned. Work to clarify these questions is urgently needed.

G. CLEANUP METHODS FOR LAND

Oil that is spilled on open water will, at one time or another, come ashore on beaches, tidelands, mudflats, and rocky headwalls. In addition, strictly land-based spills can occur from pipeline and/or tank ruptures. The extent of the contamination will be the function of the oil characteristics (as determined by the degree of weathering since the time of the spill), soil characteristics, and the environmental conditions at the time of the incident. These factors will also, to a large extent, dictate the type and extent of specific cleanup activity.

The principal oil characteristics of interest here are estimated chemical composition, viscosity, and degree of emulsification with water, ice, and snow. As a general rule of thumb, the thicker, more viscous oils will be easier to remove from loose soil such as sandy beaches and more difficult to remove from solid structures such as rocks, piling, etc. The lighter oils, on the other hand, present more serious difficulties in sandy soils, marshes, and mud flats due to the possibility of deep penetration of the supporting soil layer, and do not pose a long-term problem on solid structures from the physical adherence.

Cleanup activity is largely dictated by the basic soil characteristics of the contaminated area and the specific topographical features involved. The general soil types influencing cleanup activity are: (1) sand, whether coarse or fine, (2) rock, gravel, cobblestone, whether smooth or irregular, and the nature of the substrate on which the rock rests, (3) mud or fine silt such as in mud flats, marshes, etc., and degree of vegetation cover, and (4) tundra. Furthermore, since most objects are preferentially wetted by water, the degree and extent of contamination will depend on how dry a given impacted area is. For example, fine sand beaches which are water-saturated will not retain much oil; however, there will be a certain amount of contamination by the water-soluble aromatics in the oil. In general, we may note that the more porous the soil structure and the lighter the contaminating oil, the deeper and more pervasive the contamination.

One other point must be noted; the environmental conditions at the time of the incident may severely modify the general expectations outlined above. Rain, snow, ice, heavy surf, and wind action will usually increase the complexity of a given pollution incident. However, one may note that rain, heavy surf, and wind action will aid in the natural dispersion of the lighter fractions of a given slick or oil mass. The heavier fractions will form oil-water emulsions--the "chocolate mousse" noted at many previous spills where severe mixing actions were present.

The principal cleanup and restoration methods attempted to date in previous spill incidents may be outlined as follows:

DISPERSION PROCESSES

1. Emulsification with detergents or complexing agents.
2. Hydraulic dispersal.
3. Steam cleaning (for solid structural components).
4. Sand blasting (for solid structural components).
5. Mixing and burying on site.

REMOVAL PROCESSES

1. Burning, either direct or with aid of burning agents.
2. Direct mechanical and manual removal.
3. Removal aided by sorbents.
4. Removal aided by collecting agents other than sorbents, e.g., gelling agents, polymerization agents, etc.
5. Sand cleaning on site, e.g., fluidized beds.
6. Biodegradation.
7. Natural scouring by wind and wave action.

Each of these methods is reviewed in detail by Der and Ghormley[39] in a study for Naval Ship Systems Command.

(1) EMULSIFICATION OR DISPERSION

Emulsification can be achieved with any of a number of chemical agents which consist of molecules having one or more oleophilic (oil-seeking) locations and other locations which are hydrophilic (water-seeking). The result is a formation of a more dilute mixture of the oil, emulsifying agent, and water, whether the water is adjacent sea or stream water or applied specifically for the cleanup operation. Use of such chemicals is explicitly governed by the legal provisions of the National Contingency Plan.[32] Principal effects of dispersant applications are to increase the surface area of oil in contact with the environment (breakdown of oil mass cohesiveness, hence formation of finer droplets) and to form dispersant-oil compounds with (possibly) un[illegible]n toxicity characteristics even when the dispersant itself may be non-toxic.

Past experience with emulsifying or dispersant agents on beach surfaces indicated that the structural integrity of the beach sands will be altered. In the Ocean Eagle spill, San Juan, Puerto Rico, use of dispersants turned the beaches into quicksand; similar effects have been noted by some observers in Europe. However, although the use of emulsifyers and dispersants in the U.S. would probably not be allowed under current regulations, it is noted that European-recommended codes of practice[31] advocate such use for beach areas.

(2) HYDRAULIC DISPERSAL, STEAM CLEANING, SAND BLASTING

All these methods are based on the dilution principle with obviously increasing impact on any biota affected by these operations. Hydraulic dis-

dispersal simply involves use of high-pressure water jets to agitate the polluted areas; steam cleaning and sand blasting are obvious processes. These actions have been taken previously for cosmetic reasons. One notes, however, that, with exception of sand blasting, the treated surfaces still retain a discoloration. The primary effects of such cleanup efforts (the "under the nozzle effects") are compounded by the mechanical support activity.

(3) MIXING AND BURYING ON SITE

For high penetration areas contaminated by lighter oil products, this technique has been used, after surface material removal, to promote evaporation of remaining volatile fractions, enhance biological and physical degradation, and dilute the contaminant. Mixing may be accomplished manually or mechanically, e.g., harrowing plows.

(4) BURNING

Burning as a method of beach cleanup has been attempted at various spills in the past, e.g., Santa Barbara, Chedabucto Bay (Arrow), Portland (Tamano), with unsatisfactory results. Typically, the oil is weathered substantially by the time it comes ashore for a beach contamination incident and combustion is difficult to sustain. In addition, the residue left is more difficult to clean up than the original oil or oil emulsion. For land-based spills in the Arctic, burning is not recommended due to the complete destruction of vegetation resulting. Studies of vegetation recovery in the Arctic following fires indicate a very slow recovery as well as alterations to the ground-water, permafrost equilibrium levels.

(5) MANUAL AND/OR MECHANICAL REMOVAL

The most effective means of cleaning polluted beaches to date involve some combination of manual and/or mechanical removal aided selectively by sorbent materials. Sorbents should always be used selectively, taking into account the methods to be used for collecting the sorbent/oil mass and the nature of the sorbents. If the sorbents are not compatible with the cleanup methods to be used on a particular area, cleanup may be hindered rather than aided.

Various mechanical devices may be used to aid beach and land spill cleanup, such as motorized graders, elevating scrapers, front-end loaders, bulldozers, draglines, and dump trucks. Evaluation of selected earth-moving devices for beach cleanup was conducted by URS Research Company for EPA.[40] The effectiveness of any particular piece of equipment depends upon the type of oil and beach involved. Applicability to various Alaskan spill situations will again be strongly influenced by logistics considerations as well as disposal methods and/or sites for the recovered contaminated material.

Motorized graders are designed to move material short, lateral distances by side-casting process and not for hauling material in the direction of travel. For removing thin film, say 0.5 to 1.0 in. of oily sand or dirt, this equipment is efficient when used in combination with motorized elevating scrapers.[40] The motorized graders are used to cut and remove the surface layers and pile them into windrows which are then picked up by the elevating scrapers. If oil penetration is deeper than 1.0 in., graders should not be used.[39,40] Also, the presence of rocks or cobbles will impair the effectiveness of these methods. Terrain must be gently sloped and sufficiently large areas involved to allow for maneuvering. Because of the large size and weight of these machines, it is unlikely that they will be useful except for spill sites near roads or construction sites along pipelines, etc. Motorized elevating scrapers are useful by themselves for picking up moderate-depth contaminated material, say 1 to 9 in. in depth.

Wheeled front-end loaders are designed for digging, loading, and limited transport of material. They can be used to remove windrows left by scrapers or piles resulting from manual gathering efforts. When the penetration into the soil is deep, say 9 in. or more, these vehicles are useful for removal of the material. Because of the smaller sizes available, front-end loaders may be a useful aid to manual operations in more remote and/or restricted areas.

Bulldozers are useful for removal of large amounts of contaminated material and such vehicles are available in a wide variety of sizes. However, bulldozers typically re-work the oil into the beach as a result of spillage around the blade and track action.

The state-of-the-art for beach cleanup has been summarized by Der and Ghormley[39] as follows:

> A review of beach cleanup operations has been made. Most of the documents reviewed do not give sufficient quantitative data for the purpose of developing precise criteria for selection of procedures and equipment, or for estimating cost, equipment and manpower required. Sufficient data, however, were obtained for the purpose of selecting a number of procedures which are considered satisfactory in previous cleanup operations. These should be adequate for most of the cleanup operation.
>
> No effective techniques have been developed to remove oil from rocks. Washing with hot water can remove most of the oil from the rock surface, and the remainder can be removed by sand blasting, which is, however, slow and expensive.

Contaminated cobbles can be removed by using draglines and front-end loaders.

For beaches with sand and gravel sediment, the contaminated materials can be removed by various mechanical equipments. The selection depends on the depth of oil penetration:

1. For oil penetration of up to 1 inch, combined use of road graders and motorized elevating scrapers is most effecient.

2. For oil penetration from 1 to 9 inches, use of motorized elevating scraper only is more efficient.

3. For oil penetration depth of greater than 9 inches, wheeled front-end loaders and bulldozers can be used, wheeled front-end loaders being more effective for firm ground and bulldozers more effective for softer ground.

In general, fine sand and gravel beaches can be expected to be firm, whereas coarse sand beaches are soft and thus not likely to be able to support wheeled vehicles. The coarser the material and the lighter the oil, the deeper the oil penetration. Amount of oil is a factor in the penetration depth.

The above apply mostly for heavy oils. For light oils on rocks, most of the contaminant will be evaporated. When light oil soaks into finer material, evaporation can be enhanced by the use of beach cleaning machines or harrow plows.

The use of detergents increase the penetration of the oil and results in more contamination of the beach than originally existed. The detergents emulsify the oil in water, which makes it more toxic to the biota.

The quantity of oil spilled and the extent of the beach contamination are related to factors which affect the procedure selected for beach cleaning. Contamination of beaches from natural oil seeps has been measured at oil concentrations varying from 0.01 to 3 oz/ft^2 of beach surface (based on a 500 ft^2 area of measurement). Such a concentration of oil represents a severe local contamination, but the materials have been found to disperse in a few days by natural processes.

In the Torrey Canyon spill, oil concentrations up to 30 oz/ft^2 of sand were observed[41]. Covering the oil with fresh, clean sand was found to prevent normal hydraulic drainage of the beach, and ultimately resulted in accelerated beach erosion.

Sorbent materials provide sorption surface for the oil upon arrival at the beach, but on standing, the oil tends to drain into the sand. Disadvantages for sorbents are the costs and problems involved in gathering and disposing of the material.

Sand cleaning procedures are not sufficiently advanced to be considered for immediate use in beach cleanup. With further development, these processes may be advantageo ; for cleaning beach areas.

Burning of oil on a contaminated beach has not been effective. It is difficult to ignite the oil and to maintain the combustion. Complete combustion is not usually achieved and the residue is a heavy black mixture of tar and charcoal. The use of a torch or flame thrower to remove oil from rock outcroppings causes spalling which is hazardous to the operators and disfigures the rock surface.

A summary of equipment and methods for beach cleanup is given in Tables 6-1,2.

H. SUMMARY OF ARCTIC CLEANUP TECHNIQUES: AN EVALUATION

In the above sections, MSNW discussed in some detail the salient features of the known methods for combatting Arctic oil spills on land or offshore. Clearly the effectiveness of all techniques will be a function of how well the oil can be contained or restricted from dispersion and this in turn depends on the response logistics. Response logistics are reviewed by Battelle[27] assuming a few specific staging areas for containment and cleanup equipment; however, as the oil production and transshipment activity develops, new staging locations close to high risk areas will need to be established hence altering the response times estimated by Battelle. In the MSNW evaluation of containment and cleanup effects for the 17 study locations, the Battelle response times were used except as noted, with the understanding that if staging areas change, the corresponding logistics will change also.

Because of the (typically) long response times for the study location, the effectiveness of the majority of oil spill countermeasures is drastically reduced. In all water-based spill scenarios (except St. Matthew Island, see

TABLE 6-1 . METHOD/EQUIPMENT FOR CLEANUP OF SAND AND GRAVEL BEACHES

Size of Area	Type of Oil	Depth of Penetration	Type of Beaches		
			Fine Sand	Coarse Sand	Gravel
Large	Heavy	shallow (1/2'' to 1'')	Grader + ES	Grader + ES	--
		moderate (1'' to 9'')	ES	ES	ES
		deep (>9'')	--	Bulldozer	WFEL* or Bulldozer
	Light	--	Harrow plow or beach cleaning machine		
Small	Heavy	--	Manual removal and replacement of sand		
	Light	--	Manual removal, rake		

Notes: ES - Elevating scraper.
WFEL* - Wheeled front-end loader, for firm ground only.

TABLE 6-2 . METHOD/EQUIPMENT FOR CLEANUP OF BEACHES WITH COBBLES AND BOULDERS

Oil	Cobbles	Boulder
Heavy	Draglines or WFEL for large area. Manual removal for small area	Hydraulic and steam cleaning followed by sand blasting
Light	Hydraulic	

SOURCE: Der, J. J. and E. Ghormley, *OIL CONTAMINATED BEACH CLEANUP*, Technical Note N-1337, Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, California, April 1974.

specific discussion Section 2-10-C), it is assumed that containment boom and some type of skimming device(s) will be deployed even if the response time is long. Analysis of past spill experiences indicated that booming and skimming vary greatly in effectiveness depending on the degree to which the oil is dispersed. As noted above, boom failure due to sea (and/or ice) conditions and skimmer failure, both functionally and from a personnel safety point of view, are the principal limitations to field use noted by McLeod and McLeod[42] in their review paper. The potential effectiveness of boom and skimming devices will be strongly influenced by the expertise and Arctic field experience of the personnel employing these devices. The U.S. Coast Guard's Strike Force personnel have and will continue to test and evaluate spill response equipment in the Arctic environment. A further limitation on skimmer use (as well as manual harvesting operations) is the availability of storage and disposal of the recovered oil, particularly in more remote off-shore spills. Booms and small skimmers may be air delivered, but the problem of air deliverable storage units for skimmer support still needs to be addressed.

Experience in cold regions to date, with conventional dispersants has been disappointing due to the mixing energy requirements as well as the increased oil viscosity effects. In all likelihood, any water-based dispersant, whether conventional or self-mixing, will not be of any use in the cold waters of the Arctic Ocean and Bering Sea, depending on time of year, due to freezing problems. However, the development of self-mixing, non-water based dispersants for cold regions must be pursued as well as efforts to decrease or eliminate dispersant toxic effects and/or synergistic toxic effects of oil/dispersant mixtures. In view of the logistics times involved and (potentially) large water areas impacted, dispersant delivery by air and "crop-dusting" application may prove a viable means of oil spill treatment. A tradeoff will always exist between the toxic effects of dispersed oil and the potential for accelerated biodegradation (c.f., Section 6-B). One may also consider bacterial seeding of slicks in conjunction with dispersion; however, the effects of introducing foreign cultures into a given environmental area must be clearly understood before such action is undertaken.

Mechanical cleaning of solid structures with either sand blasting or steam cleaning equipment can only be considered for limited areas of impact, whereas oil will, to some extent, adversely affect biota indigenous to such solid structures, the mechanical cleaning will most certainly destroy the biota. The ultimate effects of such cleaning operations will depend on the rate of repopulation--at this time little data is available on repopulation dynamics for the Alaskan conditions of interest in this study.

Similarly, the use of mechanical beach cleaning devices and sand cleaning devices on site has been explored, and while they do present an effective means of beach cleaning, use cannot be advocated except for essentially sterile beach sections. In all likelihood, selective and careful manual cleanup is more preferable by far.

The most effective means of oil disposal (and in cases of heavy aggregation, cleanup) is burning, either with or without burning agents. Certainly for ice situations, this method appears to be the only viable one at this time, subject to a further investigation of smoke and combustion product effects (c.f., Section 6-B). Burning always needs to be carefully controlled and personnel safety is a major consideration when large quantities of oil are to be burned. Even though the literature indicated that in many cases burning may not work, analysis of the specific incidents shows that either the oil had spread to a thin slick or emulsion had been generated inhibiting burning.

The role that natural biodegradation processes play in the natural cleanup of oil contaminated areas has been discussed in Section 5-E-3. While it is certain that bacteria capable of degrading some hydrocarbon components of certain oils are indigenous to all the 17 sites investigated, the effectiveness and/or time required for the biodegradation process is open to question. Enhancement of bacterial action can be achieved by fertilization with nitrogen and phosphorous compounds, but further work is necessary to assess the advisability of such methods.

SECTION 6. REFERENCES

1. Edison Water Quality Research Laboratory, *OIL SPILL CONTAINMENT SYSTEMS*, Oil Spills Branch, Environmental Protection Agency, January 1973.

2. Office of Water Programs, *CONTROL OF OIL AND OTHER HAZARDOUS MATERIALS*, Environmental Protection Agency, PB 213 880, December 1971.

3. Sittig, M., *OIL SPILL PREVENTION AND REMOVAL HANDBOOK*, Noyes Data Corporation, Park Ridge, N. J., 1974.

4. National Maritime Research Center, *STATE-OF-THE-ART REVIEW OF OIL CONTAINMENT BARRIERS FOR USE AT OFF-SHORE TERMINALS*, COM-74-10212, November 1973.

5. Abrahams, R. N. and E. R. Miller, Jr., *OIL SPILL CONTAINMENT SYSTEM DEVELOPMENT AND TESTING PROGRAM*, in: "Prevention And Control Of Oil Spills," API, 1973.

6. Glaeser, J. L., *AN EFFECTIVE OIL SPILL CONTAINMENT-RECOVERY SYSTEM FOR HIGH SEAS USE*, in: "Prevention And Control Of Oil Spills," API, 1973.

7. Milgram, J. H., *PHYSICAL REQUIREMENTS FOR OIL POLLUTION CONTROL BARRIERS*, in: "Prevention And Control Of Oil Spills", API, 1973.

8. Milgram, J. H. and J. F. O'Dea, *EVALUATION OF ARBITRARY OIL POLLUTION CONTROL BARRIERS*, U. S. Coast Guard, 1973.

9. Chung, J. S., G. R. Cunningham, and J. M. Evans, *DESIGN PARAMETERS STUDY OF AN OIL-SPILL BOOM*, in: "Prevention And Control Of Oil Spills," API, 1973.

10. Wicks, M., *FLUID DYNAMICS OF FLOATING OIL CONTAINMENT BY MECHANICAL BARRIERS IN THE PRESENCE OF WATER CURRENTS*, in: "Proceedings Of The Joint Conference On Prevention And Control Of Oil Spills," API, December 1969.

11. Woolen, D. C., *MECHANICAL CONTROL OF OIL SPILLS UTILIZING A STREAMLINED BOOM*, in: "Prevention And Control Of Oil Spills," API, 1973.

12. March, F. A. and R. L. Beach, *HIGH SEAS OIL RECOVERY SYSTEM*, in: "Prevention And Control Of Oil Spills," API, 1973.

13. Lt. J. O'Brien, USCG Pacific Team, USCG National Strike Force, San Francisco, California, personal communication.

SECTION 6. REFERENCES (CONT'D.)

14. Bauer, W. H. and J. J. Bulloff, *CHEMICAL ADDITIVES TO CONTROL OIL SPILLS--A STATE-OF-THE-ART SUMMARY*, AD-779-557, January 1974.

15. Barger W. R., *LABORATORY AND FIELD TESTING OF SURFACE-FILM FORMING CHEMICALS FOR USE AS OIL COLLECTING AGENTS*, in: "Prevention And Control Of Oil Spills," API, 1973.

16. Garrett, W. D. and W. R. Barger, *CONTROL AND CONFINEMENT OF OIL POLLUTION ON WATER WITH MONOMOLECULAR SURFACE FILMS*, NRL Memorandum Report 2451, AD 744-943, June 1972.

17. Edison Water Quality Laboratory, *OIL SKIMMING DEVICES*, Environmental Protection Agency, PB 218 504, May 1970.

18. Bianchi, R. A. E. D. Johanson, and J. H. Farrell, *USE OF THE MASSACHUSETTS DIP OIL SKIMMER ON FREE SLICKS IN THE CASCO BAY (PORTLAND) SPILL*, in: "Prevention And Control Of Oil Spills," API, 1973.

19. Dorrier, J. S., *SORBENT SYSTEM DEVELOPMENTS FOR OIL SPILL CLEANUP*, in: "Prevention And Control Of Oil Spills," API, 1973.

20. Asper, J. J. and P. Bolli, *NEW DEVICE FOR REMOVING OIL SLICKS FROM THE SURFACE OF WATER*, in: "Prevention And Control Of Oil Spills," API, 1973.

21. Nebeker, E. B., S. E. Rodriquez, and P. G. Mikolij, *FREE VORTEX RECOVERY OF FLOATING OIL*, in: "Prevention And Control Of Oil Spills," API, 1973.

22. March, F. A. and R. L. Beach, *DEVELOPMENT OF A HIGH SEAS OIL RECOVERY SYSTEM*, USCG R&D Report No. 724103.06.1, 1973.

23. Beran, W. T., B. Bruch, K. R. Maxwell, et. al., *A PROTOTYPE HIGH SEAS OIL RECOVERY SYSTEM. PHASE I - SYSTEM DEVELOPMENT*, , USCG R&D Report No. 724103.06.3.

24. Bruch, B., R. R. Maxwell, and H. G. Ulgrich, *ENGINEERING CONCEPT EVALUATION PROGRAM FOR HIGH SEAS OIL RECOVERY*, USCG R&D Report No. 714103/A/004.

25. McMinn, T. J., *CRUDE OIL BEHAVIOR ON ARCTIC WINTER ICE*, Department of Transportation, USCG Project 734108, September 1972.

26. Battelle Northwest, *OIL SPILL TREATING AGENTS, A COMPENDIUM*, 1 May 1970.

27. Battelle, *LOGISTIC REQUIREMENTS AND CAPABILITIES FOR RESPONSE TO OIL POLLUTION IN ALASKA*, USCG Report CG-D-97-75, March 1975.

28. Canevari, G. P., "Oil Spill Dispersants--Current Status And Future Outlook," *PROCEEDINGS OF API/EPA/USCG JOINT CONFERENCE ON PREVENTION AND CONTROL OF OIL SPILLS*, June 15 thru 17, 1971.

29. Canevari, G. P., "Development Of The Next Generation Chemical Dispersants," *PROCEEDINGS OF API/EPA/USCG JOINT CONFERENCE ON PREVENTION AND CONTROL OF OIL SPILLS*, March 25 thru 27, 1973.

30. Canevari, G. P., *A REVIEW OF THE UTILITY OF SELF-MIXING DISPERSANTS IN RECENT YEARS*, submitted to "Conference On Prevention And Control Of Oil Pollution," March 25 thru 27, 1975.

31. Beynon, L. R., *CODES OF PRACTICE FOR DEALING WITH OIL SPILLS AT SEA AND ON SHORE: A EUROPEAN VIEW*, in: "Proceedings Of API/EPA/USCG Joint Conference On Prevention And Control Of Oil Spills," API, 1973.

32. Art. 2,000, "Schedules Of Dispersants And Other Chemicals To Treat Oil Spills," Annex X of the *NATIONAL OIL AND HAZARDOUS SUBSTANCES POLLUTION CONTINGENCY PLAN*, August 1975.

33. Battelle Northwest, *DEVELOPMENT OF A LABORATORY METHOD FOR MEASURING EFFECTIVENESS OF OIL SPILL DISPERSANT*, API contract 212300345, May 1973.

34. Battelle Northwest, *EFFECTS OF OIL AND CHEMICALLY DISPERSED OIL ON SELECTED MARINE BIOTA--A LABORATORY STUDY*, API contract 212300429, June 1973.

35. Request for Proposal No. CG-33, 755-A, U. S. Coast Guard, 9 May 1973.

36. Corins, E. R., *CHEMICAL GELLING AGENTS AND DISPERSANTS*, Esso Research and Engineering Company, 20 May 1970.

37. Fuller, H. I., "The Use Of Floating Absorbents And Gelling Techniques For Combatting Oil Spills On Water," *J. INST. PETROL.*, 57, 1971.

38. Dewling, R. T. and J. S. Dorrier, "Handling Oil Spills By Chemical Treatment," *AICHE SYMPOSIUM SERIES*, 68, 1972.

39. Der, J. J. and E. Ghormley, *OIL CONTAMINATED BEACH CLEANUP*, Civil Engineering Laboratory, Naval Construction Battalion Center, Technical Note N-1337, April 1974.

40. URS Research Company, *EVALUATION OF SELECTED EARTHMOVING EQUIPMENT FOR RESTORATION OF OIL-CONTAMINATED BEACHES*, PB 206 693, 1970.

41. Taylor W., *TORREY CANYON EXCERCISE MOP UP*, Admiralty Oil Laboratory, Fiarmile Coehaum Survey, March 1968.

42. McLeod, W. R. and D. L. McLeod, *MEASURES TO COMBAT OFFSHORE ARCTIC OIL SPILLS*, presented at "The Fourth Annual Offshore Technology Conference," Paper No. OTC 1523, May 1 thru 3, 1972.

43. Koburger, C.W., and J.H. Getman, "Oil Spill Problems in Cold Climates: The Coast Guard Attacks The Alaskan Oil Spill Problem, *NAVAL ENGINEERS JOURNAL*, December 1974.

SECTION 7. MATRIX METHOD FOR IMPACT EVALUATION

A matrix evaluation technique was adopted to simplify the characterization of complex system scenarios. This section of the report discusses general aspects of matrix methodology and examples of past matrix uses to characterize the environment, the evaluation logic for this study, the study matrix, and its meaning and interpretation.

It is important to bear in mind the following in regard to the approach adopted for analyzing impact of spilled oil in the Alaskan environment:

- The matrix values do not have a known correlation with any quantified measure, such as dollar cost. They are only relative values to be compared with each other.
- All oil spills are assumed to be detrimental. They waste a scarce resource, introduce toxic materials into the environment, and are costly to contain and clean up.
- The evaluation is made from the perspective of man. This is particularly evidenced in judgments on importance of species.
- The analysis is applied to single events only. The effect of chronic spill histories is beyond the scope of this study.

A. GENERAL ASPECTS

Basically, a matrix is a logic tool used to characterize an object. Matrices are used to represent objects which are described by independent components.[1] For example, a topographical map is a matrix representation of discrete values of altitude occurring in a bounded area.

If we say that an object, A, is a function of variables b, c, d, and e, i.e.,

$$A = F(b,c,d,e)$$

where F is the functional relationship, then A can be described by the matrix $\{a_{ijk\ell}\}$, comprised of the set of all discrete values of A derived by

$$a_{ijk\ell} = F(b_i,c_j,d_k,e_\ell)$$

where b_i, c_j, d_k, and e_ℓ are discrete values of the continuous variables and $a_{ijk\ell}$ are the elements of the matrix characterizing A.

The dimension of a matrix was defined by the number of independent variables and the size of the matrix by the numbers of discrete values of the independent variables. For example, if there are four independent variables with 10, 7, 20, and 2, discrete values of each variable, then the matrix is called a four-dimensional matrix of size 10 x 7 x 20 x 2. This particular example is thus a matrix with 2,800 elements.

The attraction of using a matrix lies in characterizing a complex object depending on variables which can have an infinite number of values by describing a finite set of elements depending on a finite number of values of the variables.

B. MATRIX CHARACTERIZATION OF THE ENVIRONMENT

The problem with assessing the state-of-the-environment can be called the problem of quantifying the unquantifiable. Measures exist for some environmental parameters (e.g., aspects of air quality and water quality), but the number of measurements and degree of coverage is limited by time and monetary constraints. Other aspects, for example aesthetics, depend greatly on individual human perception and thus are measurable only in a gross sense. Matrix evaluation of the environment is attractive due to the magnitude and complexity of the parameters involved.

Matrix methods have been used in the past in evaluation of aspects of the environment.[2-5] Burnham, et al.,[2] used a "decision matrix" to evaluate alternatives of design and site locations for nuclear power plants. They used a linear model, assigning technical ratings, a_{ij}, for the i^{th} criterion and the j^{th} site/design option and weighting each criterion with a social value, v_i. The resultant rating for the j^{th} option is then represented by the sum,

$$\sum_{i=1}^{n} v_i a_{ij}$$

where n = the total number of criteria.

In examining the assumption of linearity of values, they discussed the concept of marginal utility applied to environmental "commodities." As an example, they used dissolved oxygen as a measure of water quality. This is illustrated in Figure 7-1. The marginal utility of the "next unit" of water quality is given by the slope of the curve. In the illustration, the marginal utility decreases with increasing water quality. Burnham, et al.[2] discussed three regions in the water quality curve, very low water quality--Region A, median--Region B, and very high--Region C. They pointed out that since water quality statutes eliminate consideration of Region A for a potential site and since design economics would preclude consideration of

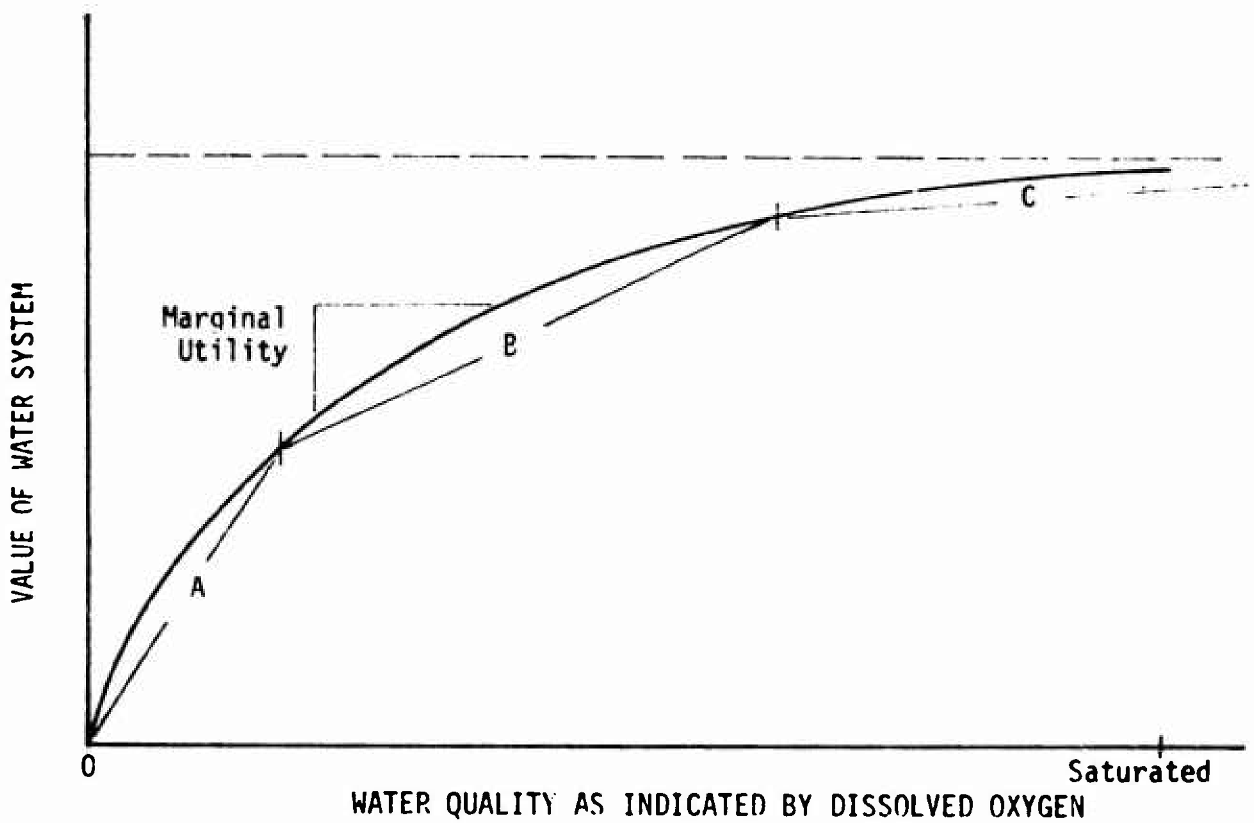


FIGURE 7-1. AN ILLUSTRATION OF THE MARGINAL UTILITY OF INCREASING WATER QUALITY

areas of very high water quality (Region C), Region B covers the degree of water quality applicable to their particular concern. In this region, they argued that the slope can be approximated by a straight line so that marginal utility of water quality has the same value throughout Region B. These considerations offset the very strong dependence of value on the overall level of water quality.[2] The assumption that values of environmental parameters are linear is a gross approximation which is not justifiably applicable to systems of very poor quality or very high quality.

Booz-Allen, Inc.[3] discussed the application of matrix evaluation methods to the analysis of "Quality of Life" (QOL). QOL encompasses both human and natural environment as viewed from the individual's perspective. They pointed out that the quality of the environment is dependent on the values of the society and the costs willing to be borne by the citizens. In a manner similar to Burnham, et al., Booz-Allen, Inc. postulated[3] a form for the QOL index by

$$QOL = f(I_1, I_2, \ldots, I_n)$$

where I_1, I_2, etc., are satisfaction indicators. "A key factor in developing environmental QOL components is weighting them. This is done through a series of trade-off analyses."[3] Given the weighting factors (w_i), the resulting expression for QOL is

$$QOL = \sum_{i=1}^{n} w_i I_k$$

which is directly analogous to the Burnham, et al., technical rating aggregate. Booz-Allen also discussed the problems of individualistic viewpoints and number of potential measurements as they bear on development of weighting factors.

Whipple approached the evaluation of the Delaware Estuary System[4] from a matrix utilization position. He stated, "...although there are many different approaches and different points of view regarding environmental quality, the problem of evaluating is not an insuperable one. Many of the relevant parameters are possible of description and some of them are evaluable in money terms."[4]

Whitman, et al.,[5] developed an environmental evaluation system aimed to be broad enough to include all relevant environmental measures and indicators. The system consists of four levels made up of four major categories, 17 environmental components, and 66 environmental parameters. Each parameter is additionally broken down into one or more specific measurements, as appropriate. Weighting factors for the various elements are derived via a Delphi technique.

MSNW used an environmental rating matrix to analyze potential power facility sites.[6] Five major categories were selected as a basis and these were broken into a total of 14 sub-components. Rating values for the components were defined, and weighting factors were assigned following a review of issues raised during prior developments and the nature of the power facility. The system was used on a relative basis to point out those sites (out of a list previously identified) which would merit first considerations in detailed environmental study and siting interest.

The present study is concerned with evaluating the environmental impact of oil spills on the Alaskan environment at 17 selected sites. The components and parameters which come to mind to describe the Alaskan environment at these sites are complex, continuous, changing, and numerous. Precise measurements, if they could be made, would probably vary over many orders of magnitude. The decision was made in the beginning to use an environmental matrix analysis approach. The following paragraphs detail that approach.

C. ALASKAN OIL IMPACT EVALUATION

The discussion which follows addresses the evaluation logic and then the development of the study matrix. The specific tasks encountered included the definition of the evaluation logic, the selection of categories and components of the matrix, the selection of indicators, and the definition of weighting factors and values.

The definition of values recalls the problem of quantifying the unquantifiable. Each particular matrix evaluation for a given spill scenario at a particular site has value only in relation to all the other matrix evaluations. This is a direct result of the need to use gross value estimates for many of the parameters. The number assigned to a particular result has no known correlation with some single, precise measure, like dollar cost. The number only serves to indicate whether it is worse than another scenario or not as bad as another scenario.

The following general observations, assumptions, and caveats should be kept in mind in regard to the analysis:

- All oil spills are assumed to be detrimental because they waste a scarce resource and they introduce a toxic material into the environment. Thus, the range for the scenarios should extend from bad to very bad.

- The general observation of ecosystem stability correlated with increased species divergence is addressed in estimations of short-term and long-term impact. The more species of animals and plants present and affected, the greater the short-term impact of an oil spill, and the more retentive the ecosystem, the greater the long-term impact.

- It is impossible to precisely define short-term and long-term. By short-term, we mean that period of time in which the oil is visually observable. Long-term is meant to correspond to the time during which the area recovers to its original state.

- The analysis is applied to single events only. The question of the effect of chronic spills is beyond the scope of the study.

- All judgments on environmental importance, etc., are subjective - viewed from man's perspective.

- The analysis uses estimates of effects on only biota to characterize the environmental impact of oil.

(1) EVALUATION LOGIC

In order to clarify the evaluation procedure before employing it at the study sites, a logic chain was constructed. This consisted of a progressional set of questions to be applied to each scenario. Tables 7-1 and 7-2 show the question sets for spills without and with cleanup. Figure 7-2 illustrates the process. Beginning with the cataloging of the habitats at the spill area, the spill scenario is developed through the computer simulation according to the type of oil, the volume spilled, and the wind and current conditions. The information on slick location with time is then analyzed for degree of habitats impacted, i.e., organisms reached by the oil.

TABLE 7-1. LOGIC PROCESS TO DECISION ON BIOLOGICAL IMPACT

A. SPILLS WITHOUT CLEANUP

(1) Is the organism at the site at the time of the spill?

(2) Is the organism (at any life stage) located at the site in a position to be contacted by the oil product?

(3) Does the oil product reach the waters of the sea? (Special situation where fast ice keeps oil products from the water.)

(4) How sensitive is the organism to oil products?

(5) How and when does the oil come into contact with the organism? (Physical, chemical contact, or both.)

(6) Can the organism sense and escape the oil product?

(7) Is the organism (a) injured by the oil product (including disruption of senses, behavior, etc.), (b) killed by the oil product, or (c) not injured at all?

(8) Assuming (a) or (b) occur, how is the local population of those organisms impacted in the short term?

(9) If impacted in the short term, what is the capability of the organisms' population to recover? Judge the impact in the long term. Such factors are involved as:

   (a) The numbers of the organism in the world, state, and local area (spectrum range from extremely endangered species to very abundant organisms) and the numbers killed or injured.

   (b) Method and timing of reproduction.

   (c) Feeding methods and selected foods.

   (d) Mobile or sessile nature of the organism.

   (e) Habitat occupied by the organism involved.

   (f) Environmental retention of disruptive oil products (most retention: salt marsh-mud areas, least retention: open coast of solid rock).

TABLE 7-2. LOGIC PROCESS TO DECISION ON BIOLOGICAL IMPACT

B. SPILLS WITH CLEANUP

(1) Is the organism at the site at the time of the spill?

(2) Is the organism (at any life stage) located at the site in a position to be contacted by the oil product or any aspect of the cleanup scenario?

(3) Does the oil product reach sea water or is it blocked by fast ice or totally or partially prevented from reaching sea waters by the cleanup method imposed?

(4) Is the oil product's area of influence reduced over the scenario without cleanup?

(5) How sensitive is the organism to the oil product or any aspect of the cleanup operation?

(6) How and when does the oil come in contact with the organism?

(7) How does the cleanup operation "contact" the organism?

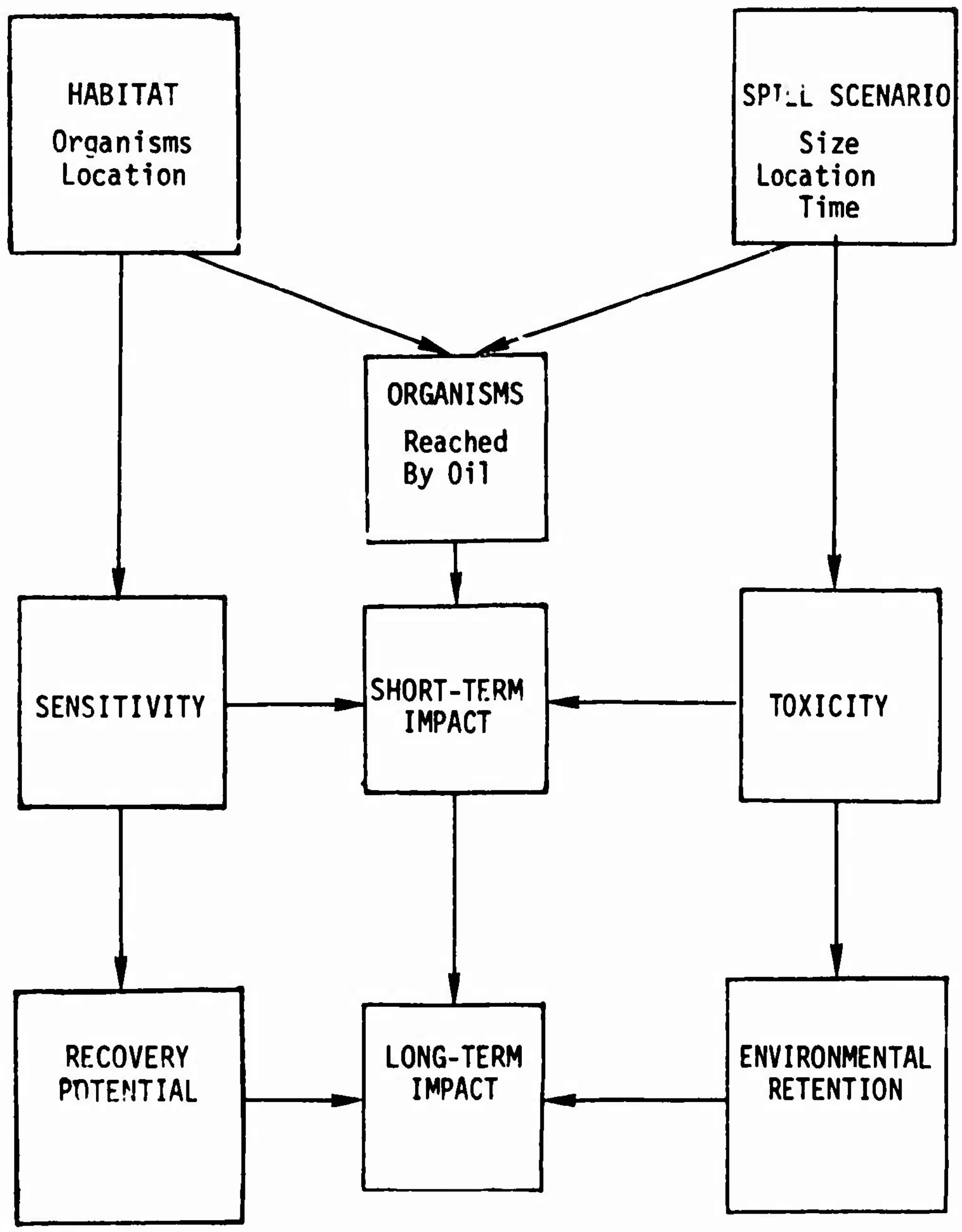
(8) Can the organism escape the oil product or disruptive cleanup operation?

(9) Is the organism (a) injured by the oil product or cleanup operation (including disruption of senses, behavior, etc.), (b) killed by the oil product or cleanup operation, (c) or not injured at all?

(10) Assuming (a) or (b) occur, how is the local population of those organisms impacted in the short term?

(11) If impacted in the short term, what is the capability of the organisms' population to recover? Judge the long-term impact (see factors involved listed in Spills Without Cleanup, Number 9 (a) through (f)).

FIGURE 7-2. LOGIC PROCESS FLOW DIAGRAM



Information on sensitivity of each organism to oil fractions and time/toxicity of the spill is plugged in to estimate the short-term impact. Estimations of the recovery potential of the habitat's organisms and the environmental retention of the oil are then applied to estimate the degree of long-term impact.

(2) STUDY MATRIX

The study matrix was defined by three independent major categories: biota, importance of species, and spill/cleanup impact. Spill/cleanup impact is comprised of short-term and long-term impact. Species importance is broken down into four components: commercial, recreational, subsistence, and ecological importance. Biota are broken down into eight components by habitat: pelagic, subtidal sand/mud, subtidal rock/gravel, intertidal sand/mud, intertidal rocky, intertidal cobble/gravel, freshwater river, and terrestrial. Each of these habitats is characterized by indicator species and species groups which were felt to be important and for which some data existed in the literature available. The matrix characterizing each spill scenario/impact is thus a three-dimensional matrix of size 2 x 4 x 117, consisting of 936 elements.

(a) VALUES AND WEIGHTING FACTORS

The parameters selected to characterize potential oil impact were not amenable to precise measurement. Thus, the parameters were quantified in a gross sense.

The matrix was developed with two specific goals in mind--(1) to allow the relative ranking of the spill scenarios by degree of impact, and

(2) to indicate potential impacts to sensitive and important species and habitats. To accomplish this, a list of parameters was developed along with specific definitions of the gross measures for each parameter. Each scenario was measured with this matrix format.

The following paragraphs discuss the parameters and weights and values chosen. The measures chosen are neither magic nor sacred, nor does MSNW claim that the matrix format is the best one for the task. It simply reflects the study team's best efforts with the available knowledge.

The measures were decided upon and fixed before application to any scenario. This was done to avoid biasing the final ranking results by re-adjusting the measures after seeing what they were yielding.

As previously mentioned, three major independent categories were used to characterize the environmental impact: biota, species importance, and spill/cleanup impact. Biota was characterized by eight habitat types which were parameterized by a list of species and groups of species. This is shown in Table 7-3. Each site is characterized by habitats, using a relative measure of the abundance of each species. Values were assigned according to the abundance rating as shown in Table 7-4. The ratings do not have precise definition limits because of the uncertainty in measured animal populations. The ratings are a relative measure for each species of its own population distribution. Species tended to be either widely dispersed or highly localized.

For widely dispersed species, i.e., found in many areas, average populations is roughly defined as the mean of the population density per unit area from measurements over many sampling sites. Minor population thus means

TABLE 7-3. BIOTA CHARACTERIZATION--HABITATS AND COMPONENT SPECIES LIST

I. PELAGIC HABITAT

Phytoplankton
Zooplankton
Ichthyoplankton
Seaweed (floating)
Greenlings
Pacific sandlance
Herring
Smelt
Crab Larvae
King salmon
Chum salmon
Sockeye Salmon
Pink Salmon
Coho Salmon
Rainbow/Steelhead trout
Dolly Varden
Northern Fur seal
Ringed seal
Ribbon seal
Bearded seal
Harbor seal
Sea lions
Walrus
Whales
Sea otter
Polar bear
Other marine mammals
Seabirds

II. SUBTIDAL SAND/MUD HABITAT

Cods
Sculpins
Starry Flounder
Other flatfish
Pacific sandlance
Miscellaneous marine fishes
Dungeness crab
Shrimp
Razor clam
Other bivalves
Other marine invertebrates

III. SUBTIDAL ROCK/GRAVEL HABITAT

Seaweed (floating)
Seaweed (subtidal)
Chum salmon
Pacific halibut
Flatfish
Greenlings
Rockfish
Walleye pollock
Other marine fishes
King crab
Tanner crab
Scallop
Other marine invertebrates

IV. INTERTIDAL SAND/MUD HABITAT

Eelgrass
Pacific sandlance
Razor clam
Softshell bivalves
Invertebrate infauna
Marine mammal rookeries
Shorebirds
Geese
Ducks
Swans

V. INTERTIDAL ROCKY HABITAT

Seaweed (intertidal)
Greenlings
Herring
Sessile marine invertebrates
Miscellaneous crustaceans
Other invertebrates
Shorebirds
Sea ducks
Marine mammal rookeries

TABLE 7-3. (CONT'D)

VI. INTERTIDAL COBBLE/GRAVEL HABITAT

Seaweeds (intertidal)
Smelt
Hardshell bivalves
Crustaceans
Gastropods
Shorebirds

VII. FRESHWATER RIVER HABITAT

Aquatic vegetation
Aquatic invertebrates
King salmon
Chum salmon
Sockeye salmon
Pink salmon
Coho salmon
Rainbow/Steelhead trout
Dolly Varden
Whitefish
Arctic grayling
Pike
Sticklebacks
Other fishes
Ducks
Geese
Swans
River otter
Mink
Muskrat
Other aquatic mammals

VIII. TERRESTRIAL HABITAT

Tundra
Riparian vegetation
Strand vegetation
Other vegetation
Brown bear
Black bear
Wolverine
Wolf
Moose
Caribou
Deer
Bison
Muskox
Sheep
Goats
Other mammals
Raptors
Ptarmigan
Other birds

TABLE 7-4. SPECIES ABUNDANCE RATING VALUE

Not Present	--	0
Minor Population	--	1
Moderate Population	--	3
Average Population	--	6
Abundant Population	--	10
Extremely Abundant	--	15

"much less" than the average population, moderate would be "slightly less," abundant would be "more than average," and extremely abundant would be "very much more."

For highly localized species, the ratings--minor, moderate, and average--do not apply. The species is either not there or there and the ratings are accordingly "not present" or "abundant/extremely abundant."

Species Importance is a set of weighting values which are applied to the biota. The importance values are measured from the human perspective and were characterized by relative estimates of commercial value, recreational use, subsistence importance, and ecological importance of each species. The weighting value ratings are shown in Table 7-5. The "protected species" and "endangered species" ratings are applied only in the ecological importance column.

TABLE 7-5. SPECIES IMPORTANCE RATING WEIGHT

No Importance in Category	--	0
Minor Importance in Category	--	1
Moderate Importance in Category	--	2
Major Importance in Category	--	3
Protected Species (Ecology Only)	--	5
Endangered Species (Ecology Only)	--	10

Again, the rating definitions are not precise but are only gross measures. For example, moderate commercial importance would apply to a species that contributes to the support of an industry, but if removed would not wipe out the industry. Major commercial importance would apply to a species that if removed would wipe out an industry. Moderate ecological importance would apply to a species that is a noticeable component of the food chain; major ecological importance would apply to a species that is very important in the food chain and which one or more other species depend on.

Oil Spill/Cleanup Impact is the final set of weighting values applied to characterize each scenario matrix. Again, these are characterized by gross estimations.

The estimations are based on the spill scenario information developed by the oil slick drift simulation model. This information on oil location and composition versus time is used to estimate the degree of short-term habitat impact via the density of organisms contacted by the oil, the sensitivity of the organisms, and the toxicity of the oil. The resulting estimate of short-term impact for each species is rated and weighted according to Table 7-6. The modifications in impact for the cleanup scenario are similarly estimated.

TABLE 7-6. OIL SPILL/CLEANUP SHORT-TERM IMPACT RATING WEIGHTS

No Impact	--	0
Minor Impact	--	1
Moderate Impact	--	4
Major Impact	--	9
Total Impact	--	16

Minor impact corresponds to a few members of the species killed or affected, moderate impact corresponds to a noticeable number of the species members killed, and major impact corresponds to many of the members of the species killed. Total impact corresponds to enough members killed that the breeding stock of the species is seriously affected.

Evaluation of the long-term impact is then made. Environmental retention of oil is estimated according to the type of beach or bottom material contacted,and the recovery potential of affected species is estimated based on the degree of mobility, the effect on the breeding stock, and the distance from potential reseeding populations. Potential long-term impacts were given greater weight than short-term impacts. The weighting factors are shown in Table 7-7.

TABLE 7-7. OIL SPILL/CLEANUP LONG-TERM IMPACT RATING WEIGHTS

Complete Recovery	--	0
Major Recovery	--	1
Moderate Recovery	--	8
Minor Recovery	--	27
No Recovery	--	64

Moderate recovery corresponds to noticeable differences in population levels following impact which recover to normal in a few breeding cycles without substantial spin-off effects on other species populations or human uses. Major recovery would be noticeable population difference only for the first breeding cycle after impact. Minor recovery would be noticeable population differences for several to many breeding cycles with spin-off effects. No recovery corresponds to eliminating the ecological and human utility of the species for a significant portion of a man's lifespan. It does not necessarily mean that the species is wiped out forever.

(b) TOTAL MATRIX RATING

Each scenario at each site is characterized by its matrix. Each matrix is composed of 936 elements depending on biota, species importance, and impact.

A typical matrix element, $m_{jk\ell}$, can be described by

$$m_{jk\ell} = \alpha_{j\ell}\beta_{k\ell}s_{\ell}$$

where

$\alpha_{j\ell}$ = spill impact weighting factor for short-term (j=1) or long-term (j=2) on the ℓth species.

$\beta_{k\ell}$ = species importance weighting factor for the kth importance category and the ℓth species.

and

s_{ℓ} = abundance rating value for the ℓth species or group of species (117 in all)

The particular matrix is thus characterized by the set

$$\{m_{mk\ell}\}$$

$$j = 1\text{-}2;\ k = 1\text{-}4;\ \ell = 1\text{-}117$$

In order to compare the relative impact typified by each matrix, a scheme was developed to derive a total impact number for each matrix. Each element represents an impact value for a particular species.

In the manner of Burnham, et al.,[2] and Booz-Allen, Inc.,[3] MSNW assumed that for total short-term (ST) and total long-term (LT) impacts, the elements are linearly additive. Thus,

$$ST = \sum_{\ell=1}^{117} \left[\alpha_{1\ell} \cdot \left(\sum_{k=1}^{4} \beta_{k\ell} s_{\ell} \right) \right]$$

and

$$LT = \sum_{\ell=1}^{117} \left[\alpha_{2\ell} \cdot \left(\sum_{k=1}^{4} \beta_{k\ell} s_{\ell} \right) \right]$$

However, ST and LT were not felt to be simply additional to yield total impact, T. This is because of the different time frames of the two terms.

In economics, future income is discounted to yield a "present value." This is because a future income of $100, for example, is not the same as having $100 in one's pocket. The $100 "in the pocket" can be deposited in a savings account to earn interest. The interest earned during the time until receiving the future income represents the difference in value the latter must be discounted.

Analogously, long-term impact should be "discounted" to a "present value" to put it on the same footing as short-term impact. The problem is that there is no procedure for the discounting. It is also clear that "discounting" is not the proper adjective. Long-term impact does not necessarily have to be decreased in value in calculating its "present value." This is simply a reflection of the uncertainty in regard to necessary breeding stocks of species and continued ecosystem viability. In brief, long-term effects may be many times more important than short-term effects.

Additionally, the study team had to address the problem of distance. The spills are hypothesized to occur in specific locations. The drift model traces out the location of the oil slick for the scenario. The estimate of the organisms hit is then made. However, for highly mobile organisms, it was apparent that there was a problem in defining the regional extent of the population around the spill site that should be considered.

It was obvious that a large breeding population next to the damaged population was more important for reseeding than a population which was halfway around the world. Thus, not only time discounting of impact had to be considered but distance discounting also.

It was felt that both problems were related to the recovery potential of each species. The greater the recovery potential, the less the long-term impact. The closer additional unaffected populations, the greater the recovery potential. Thus, it was decided that long-term impact should be discounted by the inverse of recovery potential.

Since environmental retention and species recovery potential were estimated to develop long-term impact from short-term impact, it was felt that a reasonable relative measure of the inverse of recovery potential was given by:

$$(\text{Recovery Potential})^{-1} = LT/ST$$

Thus, the total impact rating, T, was defined as the sum, over all species, of the short-term impact plus the ratio of long-term to short-term times the long-term impact.

$$T = \sum_{\ell=1}^{117} ST_\ell + \left(\frac{LT_\ell}{ST_\ell}\right) \cdot LT_\ell$$

(c) EXAMPLE MATRIX

Table 7-8 presents an example of the application to the Alaskan sites. This table illustrates the impact assessment for one habitat (the pelagic habitat) at Valdez Narrows during the Summer, with an assumed instantaneous release of 50,000 barrels of crude oil.

The pelagic habitat is described by a list of 28 species groups, listed on the left side of the table. The Abundance evaluation column immediately follows, under FACTORS. The INV. column under Abundance represents the population inventory, i.e., it is the evaluation of species population as per Table 7-4. The CONF. column under Abundance stands for Confidence Rating. This rating describes the level of certitude of the inventory number as follows:

CONFIDENCE RATING

A - Actual tabulated data exist on the species at the site.

E - Inventory value is extrapolated from actual data reasonably near the site or similar to the site.

H - Inventory value is hypothesized.

P - Based on personal knowledge of a member of the study team.

The next column set under FACTORS are the Importance columns for commercial (COM.), recreational (REC.), subsistence (SUB.), and ecological (ECOL.) importance weighting values. The weighting values are tabulated in Table 7-5. In the example, the "star" under ECOL. for Whales equals 10 (endangered species).

TABLE 7-8. EXAMPLE MATRIX EVALUATION RESULTS

U.S. COAST GUARD OIL SPILL PREDICTION STUDY
EVALUATION MATRIX

AREA	VALDEZ NARROWS
SEASON	SUMMER
SPILL SIZE	50,000 BBLS.
SPILL TYPE	CRUDE OIL
SPILL MODE	TANKER CASUALTY
RELEASE TYPE	INSTANTANEOUS
SPILL CLEANUP	NO

HABITAT.SPECIES	FACTORS									RESULTS		
	ABUNDANCE		IMPORTANCE				IMPACT			IMPACT		
	INV.	CONF.	COM.	REC.	SUB.	ECOL.	S.TRM	L.TRM	S.TRM	L.TRM	RSLT.	
1. PELAGIC												
1. PHYTOPLANKTON	6	A	0	0	0	3	4	1	72	18	77	
2. ZOOPLANKTON	6	A	0	0	0	3	4	1	72	18	77	
3. ICHTHYOPLANKTON	6	A	0	0	0	2	4	1	48	12	51	
4. FLOATING SEAWEED	10	H	0	0	0	2	4	0	80	0	80	
5. GREENLINGS	3	H	0	0	0	2	0	0	0	0	0	
6. PACIFIC SANDLANCE	3	H	0	0	0	3	1	0	9	0	9	
7. HERRING	10	A	3	0	0	3	9	8	540	480	967	
8. SMELT	3	A	1	1	1	3	9	1	162	18	164	
9. CRAB LARVAE	6	E	0	0	0	2	9	8	108	96	193	
10. KING SALMON	1	A	1	2	1	2	4	1	24	6	26	
11. CHUM SALMON	6	A	2	2	1	2	4	1	168	42	179	
12. SOCKEYE SALMON	3	A	2	2	1	2	4	1	84	21	89	
13. PINK SALMON	10	A	3	2	1	2	4	1	320	80	340	
14. COHO SALMON	6	A	3	2	1	2	4	1	192	48	204	
15. RAINBOW-STEELHEAD TROUT	6	H	0	1	0	1	9	8	108	96	193	
16. DOLLY VARDEN	10	H	0	2	0	1	9	8	270	240	483	
17. NORTHERN FUR SEAL	3	A	0	0	0	5	1	0	15	0	15	
21. HARBOR SEAL	10	A	0	0	0	5	1	0	50	0	50	
22. SEA LIONS	10	A	0	0	0	5	0	0	0	0	0	
24. WHALES	10	A	0	0	0	4	0	0	0	0	0	
25. SEA OTTER	6	A	0	0	0	5	4	1	120	30	128	
27. OTHER MARINE MAMMALS	10	A	0	0	0	5	0	0	0	0	0	
28. SEABIRDS	15	A	0	0	0	5	9	1	675	75	683	
									3117	1280	4008	

The remaining column set under FACTORS are the Impact columns for Short-Term (S.TRM) and Long-Term (L.TRM) rating weights. These impact weight values are tabulated in Tables 7-6 and 7-7.

The remaining columns on the right-hand side of the table are the Results. These include the short-term and long-term impact scores for each species and the resultant impact score. The generation of these scores is illustrated below using two species from the table:

SPECIES	ABUNDANCE		IMPORTANCE		IMPACT			RESULT	
					ST	LT		ST	LT
Herring	10	x	[3+0+0+3]	x {	9		=	540	
						8	=		480
Chum Salmon	6	x	[2+2+1+2]	x {	4		=	168	
						1	=		42

	RSLT
Herring	$540 + (480)^2/540 = 967$
Chum Salmon	$168 + (42)^2/168 = 179$

(3) HUMAN EVALUATION INPUT

Three areas were of concern in the evaluation process for this study. The first two areas pertained to the accuracy of the matrix input data; the last area pertained to the evaluation of the matrix results. The matrix input values were put through a modified Delphi process. The evaluation of the matrix results was basically a relative site-by-site, habitat-by-habitat comparison of the impact scores in a search for patterns and general impact level.

(a) DELPHI PROCESS ON MATRIX VALUES

The modified Delphi process used by MSNW was based on an initial derivation of consensus through contributions from the study team members as individuals, with subsequent iterations done collectively rather than continuing with non-confrontative individual input. It was felt that this process was better adapted to the needs of the study in utilizing the expertise of the individuals comprising the study team.

The process was used to correlate as best as possible the gross measures of abundance, importance, and impact for each species to the mass of data and knowledge available. After values were assigned for specific factors, the assignments were reevaluated by study team members, collectively and individually, as circumstances allowed.

(b) MATRIX INTERPRETATION

One of the major efforts of the study was aimed at comparing the relative impact for all the scenarios by impact score. This was intended to point out those areas, seasons, petroleum types, etc. of greatest concern.

In addition, prior to this final step, MSNW was concerned with the interpretation and meaning of the matrix results for each site, individually. The questions of concern were on whether the relationships of impact scores for each habitat made sense. The question arose because of the problem of multiplying "relative" measures. For example, the following species impacts taken from Table 7-8 illustrate the problem:

SPECIES	ABUNDANCE	IMPORTANCE COM.	REC.	SUB.	ECOL.	IMPACT ST	LT	RESULTS ST	LT	Total
Smelt	3	1	1	1	3	9	1	162	18	164
Chum Salmon	6	2	2	1	2	4	1	168	42	179

The impact of oil on smelt is greater, but, because of higher abundance, chum salmon score slightly higher. Thus, these two species contribute about equally to the relative impact for the case. The veracity of this conclusion is hard to judge due to the unquantifiable aspects of environmental impact.

The problem in general is not resolved. The study methods were designed to alleviate the problem of multiplied "relative" measures by keeping the analysis on a comparative inter-site and intra-site basis.

This aspect carried over into the comparison of sites in the interpretation of the relative impact of all the spill cases. Basically, the study team reviewed the ranking list with the following questions in mind:

- Did the relative impacts on the habitats within a case make sense with the spill scenario?
- Did the relative habitat impacts correlate with other sites for similar spill sizes, seasons, and petroleum types?
- Were relative habitat differences correlated with abundance differences?
- Were seasonal differences consistent?
- Were product differences and spill size differences consistent?

These questions helped define the general conclusions discussed in the Summary.

SECTION 7. REFERENCES

1. Beaumont, R.A. and R. W. Ball, *INTRODUCTION TO MODERN ALGEBRA AND MATRIX THEORY*, Holt, Rinehart and Winston, San Francisco, 1954.

2. Burnham, J. B., et. al., *A TECHNIQUE FOR ENVIRONMENTAL DECISION MAKING USING QUANTIFIED SOCIAL AND AESTHETIC VALUES*, Battelle Pacific Northwest Laboratories, Report No. BNWL-1787, February 1974.

3. Booz-Allen Public Administration Service, *THE QUALITY OF LIFE CONCEPT: A POTENTIAL NEW TOOL FOR DECISION-MAKERS*, U. S. Environmental Protection Agency, Report No. PB 225 089, March 1973

4. Whipple, William Jr., *THE DELAWARE ESTUARY SYSTEM, ENVIRONMENTAL IMPACTS AND SOCIO-ECONOMIC EFFECTS: ENVIRONMENTAL QUALITY AND ITS EVALUATION*, National Science Foundation, Report No. PB 231 424, January 1974.

5. Whitman, I. H., et. al., *DESIGN OF AN ENVIRONMENTAL EVALUATION SYSTEM*, Battelle Columbus Laboratories, June 1971.

6. Mathematical Sciences Northwest, Inc., *ENVIRONMENTAL ASSESSMENT OF GAS TURBINE GENERATING UNITS - SITE ALTERNATIVES*, Department of Lighting, City of Seattle, February 1974.

SECTION 8. CASES SELECTED FOR ANALYSIS

The fact that oil exploration, extraction, and transport will be concentrated in certain known areas and the need for early development of spill control plans dictated that the U.S. Coast Guard focus this study on certain selected analysis cases.

A. COAST GUARD CASES AND MODIFICATIONS

The input for the study cases was provided in the program's RFP[1] and award contract (NO. DOT-CG-42913-A).[2] Minor modifications in this original input were later negotiated with the U.S. Coast Guard. For example, Alyeska Pipeline Service Co.[3] indicated that a spill volume of 50,000 barrels (one barrel = 42 U.S. gallons) was not possible at either the Yukon River or the Denali Fault crossings of the Trans-Alaska Pipeline (TAP). MSNW was directed to substitute a 4,000-bbl crude oil spill for the 50,000-bbl spill at the Denali Fault Crossing.

Tables 8-1 and 8-2 present the modified cases that were analyzed by MSNW. Figure 8-1 shows the general location in Alaska of the 13 marine sites and the 4 terrestrial sites listed in Tables 8-1 and 8-2.

B. CASE PARAMETERS

Five spill volumes were examined--100, 1,000, 4,000 (Denali Fault Crossing only), 10,000, and 50,000 barrels. A total of seven spill modes were considered as follows:

1. Tanker casualty
2. Drilling rig discharge

TABLE 8-1. SPILL INFORMATION FOR CRUDE OIL,[1] FOR BOTH SUMMER[2] AND WINTER[2] SPILLS

AREA (1)	LOCATION (2)	SPILL QUANTITY (BBLS) 50,000 (3)	10,000 (4)	4,000 (5)	1,000 (6)	100 (7)		POSSIBLE SPILL SITUATIONS[3] (8)
GULF OF ALASKA	1. Offshore Yakutat	X	X				1	Ice free, general surface transport in Gulf is onshore
					X	X	2,3,4,5,6	
	2. Valdez Harbor				X	X	3,5	Skim and brush ice in shallow areas of protected bays during Winter season.
	3. Valdez Narrows	X	X				1	
					X	X	4	
COOK INLET	4. Drift River Terminal	X	X				1	Ice in upper inlet during Winter season.
					X	X	2,3,4,5,6	
	5. Offshore Port Graham	X	X				1	Ice free.
					X	X	4,5	
	6. Kamishak Bay				X	X	2,3,4,5,6	– Ice in shallow bays during Winter Season.
BERING SEA SHELF	7. Unimak Pass	X	X				1	Ice free, high currents.
					X	X	3,4,5,6	
BRISTOL BAY	8. Offshore Port Moller		X				6	Scattered ice during winter season.
					X	X	2,5,6	
	9. Kvichak Bay		X				6	Scattered or broken ice during Winter season. Isolatedppermafrost.
					X	X	2,5,6	
BERING SEA SHELF	10. Vicinity of St. Matthew Is.	X	X				1	Ice conditions ranging from open to close pack.
					X	X	2,3,4,5,6	
NORTON SOUND	11. Offshore Nome	X	X				1	Ice conditions ranging from open to fast ice. Permafrost.
					X	X	2,3,4,5,6	
KOTZEBUE SOUND	12. Offshore Cape Blossom	X	X				1	Ice conditions ranging from open to fast ice. Permafrost.
					X	X	2,3,4,5,6	
NORTH SLOPE	13. Offshore Prudhoe Bay	X	X				1	Ice conditions ranging from open to consolidated or fast depending on season.
					X	X	2,3,4,5,6	
	14. Onshore Prudhoe Bay	X	X		X	X	2,5,6	– Tundra, permafrost.
	15. Onshore Umiat (Colville River)		X		X	X	2,5,6	– Tundra, permafrost. River frozen in Winter.
TRANS-ALASKA PIPELINE SYSTEM	16. Yukon River Crossing		X		X	X	6	– River freezes in Winter.
	17. Denali Fault Crossing		X	X	X	X	6	– Terrain may cause oil to drain into rivers, streams, lakes, or other bodies of water.

[1] Crude oil type is assumed to be that crude produced or transported from the area in question.

[2] The definition of Summer and Winter is that contained in the climatological section of Appendix B of Part F (Battelle Report).

[3] Spill situation legend:
1. Tanker casualty
2. Drilling rig discharge
3. Tanker transfer operation
4. Uncontrolled tanker ballast discharge
5. Miscellaneous spills
6. Pipeline break or leak

TABLE 8-2. SPILL INFORMATION FOR REFINED PRODUCTS,[1] FOR BOTH SUMMER[2] AND WINTER[2] SPILLS

AREA (1)	LOCATION (2)	SPILL QUANTITY (BBLS) 50,000 (3)	10,000 (4)	1,000 (5)	100 (6)	POSSIBLE SPILL SITUATIONS[3] (7)	
GULF OF ALASKA	1. Offshore Yakutat	X	X			1,7	Ice free, general surface transport in Gulf is onshore.
				X	X	5	
	2. Valdez Harbor			X	X	3,5	Skim and brush ice in shallow areas of protected bays during Winter season.
	3. Valdez Narrows	X	X			1,7	
				X	X	4	
COOK INLET	4. Drift River Terminal	X	X			1	Ice in upper inlet during Winter season.
				X	X	3,4,5	
	5. Offshore Port Graham	X	X			1	Ice free.
				X	X	4,5	
	6. Kamishak Bay			X	X	5	Ice in shallow bays during Winter season.
BEARING SEA SHELF	7. Unimak Pass	X	X			1,7	Ice free, high currents.
				X	X	5	
BRISTOL BAY	8. Offshore Port Moller		X			7	Scattered ice during Winter season.
				X	X	5	
	9. Kvichak Bay		X			7	Scattered or broken ice during Winter season. Isolated permafrost.
				X	X	5	
BERING SEA SHELF	10. Vicinity of St. Matthew Is.		X			7	Ice conditions ranging from open to close pack.
				X	X	5	
NORTON SOUND	11. Offshore Nome		X			7	Ice conditions ranging from open to fast ice. Permafrost.
				X	X	5	
KOTZEBUE SOUND	12. Offshore Cape Blossom		X			7	Ice conditions ranging from open to fast ice. Permafrost.
				X	X	5	
NORTH SLOPE	13. Offshore Prudhoe Bay		X			7	Ice conditions ranging from open to consolidated or fast depending on season.
				X	X	5	
	14. Onshore Prudhoe Bay			X	X	5	Tundra, permafrost.
	15. Onshore Umiat (Colville River)			X	X	5	Tundra, permafrost, river frozen in Winter.

[1] Refined product includes gasoline, distillate fuel oil, and residual fuel oil.

[2] The definition of Summer and Winter is that contained in the climatological section of Appendix B of Part F (Battelle Report).

[3] Spill situation legend:

1. Tanker casualty
2. Drilling rig, accidental discharge
3. Tanker transfer operation
4. Uncontrolled tanker ballast discharge
5. Miscellaneous spills
6. Pipeline break or leak
7. Barge casualty

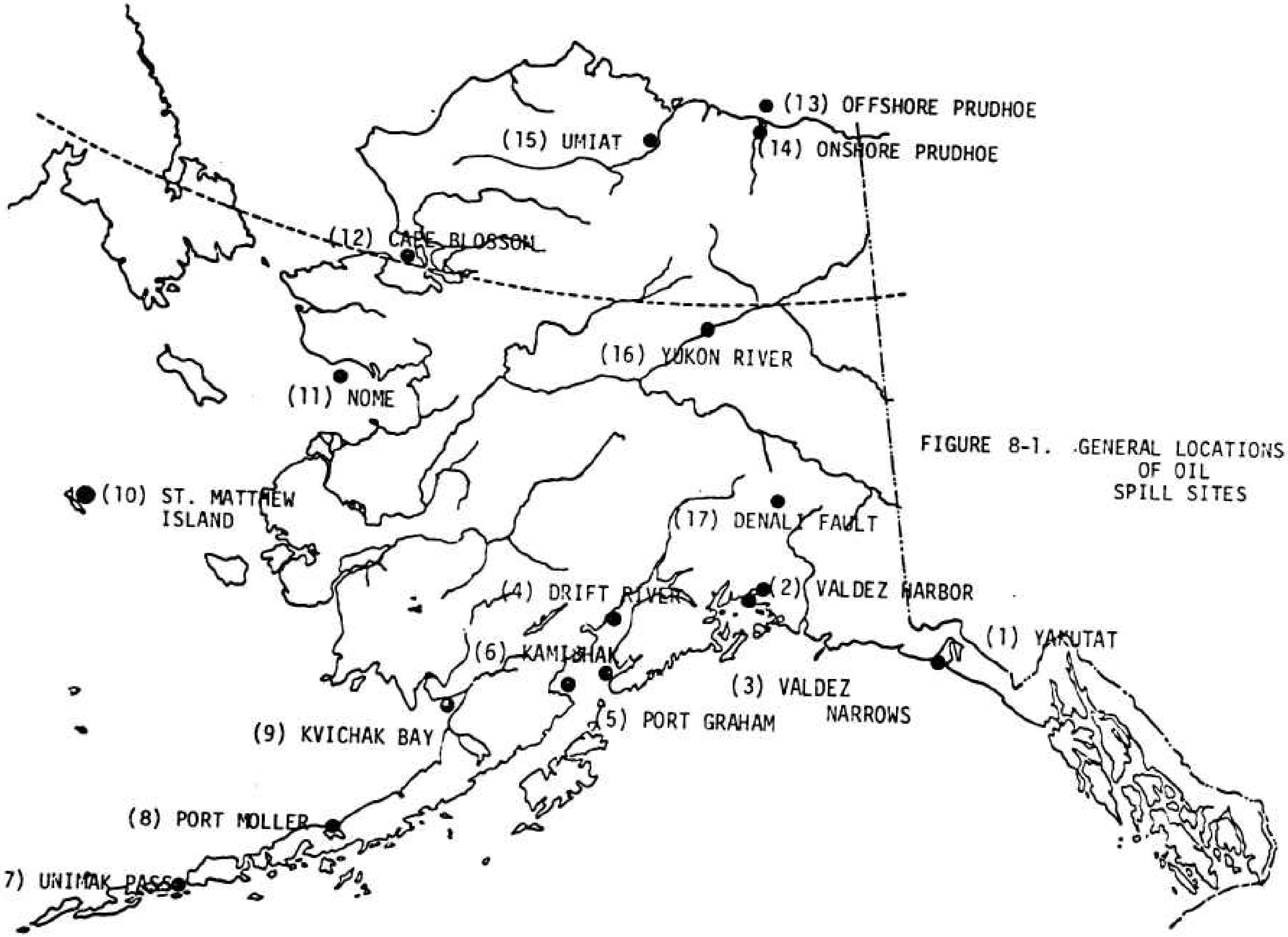


FIGURE 8-1. GENERAL LOCATIONS OF OIL SPILL SITES

3. Tanker transfer operation

4. Uncontrolled tanker ballast discharge

5. Miscellaneous spills

6. Pipeline break or leak

7. Barge casualty (for refined products and not for crude)

Additional parameters that also required definition to undertake the oil dispersion modelling and biological/natural process inventory were the exact spill site, specific oil types, and seasons.

(1) EXACT SPILL SITE

The wind, current, bathymetric, and topographic conditions at each of the 17 locations under study required that specific spill sites be selected at each general location for the purpose of a starting point for the oil dispersion modelling process. In the absence of a specific starting point, many points would have had to be modelled and this was considered to be beyond the scope of the present program.

MSNW personnel undertook a detailed review of the locations involved and the volumes and spill modes specified in Tables 8-1 and 8-2 to select specific spill sites. The following were considered in the logic process of selecting spill sites:

1. In locations having multiple spill modes, the specific spill site was dictated by the largest volume source.

2. Additional factors that influenced the selection of specific spill sites included:

- Navigation

- Shipping routes, route intersections, accident histories, critical maneuvering radii, stopping distances, hazard avoidance radii of tankers and barges.

- Natural hazards.

- Rocks, reefs, shoals, restricted channel depth, fog, storms.

- Proximity of existing terminals.

- Estimated feasible terminal locations.

- Faults in pipeline crossings.

- Water-land interface of projected pipelines.

- Projected drilling operations and supply routes.

3. In those cases where tankers and barges were identified as probable spill modes (and have the 50,000-bbl and/or 10,000-bbl spill volumes), factors relating to shipping were taken into account.

4. In cases where pipeline failures were the most probable and also the largest volume spill, the appropriate factors related to fault hazards and water-land interface hazards were taken into account.

5. In cases where none of the listed factors (in No. 2) identified a site, estimated maximum impacted area was used to define the exact spill site.

MSNW recommended precise spill sites for the marine and land sites based on the above criteria. These were subsequently approved by the U.S. Coast Guard with minor changes. The following list describes the exact spill site at the 17 Alaska locations under study.

1. Yakutat - $59^{o}36'N$, $140^{o}1'W$ - This site is at the deepest part of the entrance to Yakutat Bay closest to the city of Yakutat. The primary reason for this site is that the largest spills are from tankers and

barges (50,000 and 10,000 bbls) of the four different spill types. We assumed that captains of these vessels would travel no further than necessary to reach the open ocean consistent with the critical maneuvering radii of supertankers, i.e., turning radii and stop distances.

Note: This site was questioned by the U.S. Coast Guard as it was not initially thought to be in deep enough water to represent drill rig spills. The site was never formally moved, however. See Figure 2-7 for the location map and the exact spill site (+).

2. Valdez Harbor - $51^{o}5.56$'N, $146^{o}22.22$'W - This site is the site of the proposed terminal at the west end of Jackson Point. The spill types (transfer and miscellaneous) indicate that the only spills to be considered are between ship and shore. See Figure 2-12 for the location map and the exact spill site (+).

3. Valdez Narrows - $51^{o}3.17$'N, $146^{o}40$'W - This site is at the south end of the Narrows, in mid-channel and off of Potatoe Point. This site was selected by the U.S. Coast Guard after MSNW initially suggested a site at the north end of the Narrows in the vicinity of Middle Rock Light. The U.S. Coast Guard wanted a spill site closer to Prince William Sound and outside of Valdez Harbor. See Figure 2-17 for the location map and the exact spill site (+).

4. Drift River - $60^{o}34.44$'N, 152^{o}W - This site was selected as it is immediately east-southeast of the present Drift River terminal in the narrowest part of the channel between the mainland on the west and Kalgin Island on the east, and this is an area of (possible) congestion for traffic to and from the terminal. See Figure 2-19 for the location map and the exact spill site (+).

5. Port Graham - $59^{o}23.89$'N, 152^{o}W - This site was selected as the point closest to the entrance to Port Graham where in-transit tankers might travel. (Large tanker spills in the 10,000 and 50,000-bbl classes make up one-third of the cases.) The site is approximately 5 kilometers west of Dangerous Cape. See Figure 2-27 for the location map and the exact spill site (+).

6. Kamishak Bay - 59°11.11'N, 153°41.79'W - This site is one where we were least able to determine an appropriate point for spills. The largest spill is 1,000 barrels, with miscellaneous spills making up one-half of the cases. Since a drilling rig may be located at any point in the Bay with equal probability, the site was selected relatively close to the shoreline as the Bay to the south and west is predominantly tidal flats where spill effects might become serious. See Figure 2-32 for the location map and the exact spill site (+).

7. Unimak Pass - 54°18.38'N, 164°52.50'W - This site was selected as being approximately in the center of the Pass in the deepest water. One-half of the cases are large (10,000- or 50,000-bbl) spills from either barges or tankers. Weather conditions dictate that the center of the Pass was a likely candidate for collisions. See Figure 2-37 for the location map and the exact spill site (+).

8. Port Moller - 56°N, 160°37.87'W - The major spills are 10,000 barrels of crude oil from a pipeline and 10,000 barrels of each of the refined products from a barge. The site selected is what we believe to be the deepest part of the channel entrance to Port Moller and Hague Channel. It was assumed that the refined products were being delivered to the exploratory sites where drilling would be taking place; present leases for gas and oil exploration are primarily on the peninsula to the east and north. See Figure 2-49 for the location map and the exact spill site (+).

9. Kvichak Bay - 58°35.56'N, 157°30'W - This site was selected as the center of the channel in the Bay. The current flow out of the Bay and the prevailing winds from the southwest make this location appropriate as these two influences on oil movement tend to balance each other. The major spills here are the same as with Port Moller above. See Figure 2-57 for the location map and the exact spill site (+).

10. St. Matthew Island - 60°31'N, 172°30'W - This site was selected as the area where anticipated oil and gas development is on the northeast side of the

Island. The major spills are from tankers and barges and, therefore, a site approximately midway between the extreme ends of the Island was selected. See Figure 2-61 for the location map and the exact spill site (+).

11. Nome - $64^{o}27.22'N$, $165^{o}25'W$ - This site was selected as it was approximately 4 kilometers directly south of Nome where the depth of water exceeds 60 ft. The major spills are from tankers (10,000 and 50,000 bbls) and barges (10,000 bbls). See Figure 2-65 for the location map and the exact spill site (+).

12. Cape Blossom - $66^{o}45'N$, $163^{o}W$ - This site was chosen in the center of the channel in Kotzebue Sound approximately 22 kilometers west of Cape Blossom. The major spills here are the same as at Nome above. See Figure 2-69 for the location map and the exact spill site (+).

13. Offshore Prudhoe - $70^{o}33.06'N$, $148^{o}25.14'W$ - This site, approximately 26 kilometers north of the Prudhoe Bay shoreline, was selected as the closest point to Prudhoe in water at 60-ft depth or greater. The depth is required for tankers (spills of 10,000 and 50,000 bbls). See Figure 2-73 for the location map and the exact spill site (+).

14. Onshore Prudhoe - $70^{o}12.78'N$, $148^{o}25.14'W$ - This site, near the Deadhorse Airport, was selected as an oil well is indicated here and the site was within 1 km of the Sagavanirktok River. The largest spills are crude oil in quantities of 10,000 and 50,000 barrels from a drill rig, pipeline, or a miscellaneous spill. See Figure 2-81 for the location map and the exact spill site (+).

15. Umiat - $69^{o}28.33'N$, $151^{o}30'W$ - This site is approximately 28 kilometers downstream from Umiat on the Colville River. The location is on the north shore within Naval Petroleum Reserve No. 4. See Figure 2-83 for the location map and the exact spill site (+).

16. Yukon River Crossing - $65^{o}52.72'N$, $149^{o}42.63'W$ - This site is on the north shore on the Yukon River where the TAPS is to cross the river. A reference point at this site is Alyeska Pipeline Service Company Station No. 77+80. This pipeline will cross the Yukon River in conjunction with a state highway bridge. This area was felt to be the most vulnerable to catastrophe. See Figure 2-91 for the location map and the exact spill site (+).

17. Denali Fault Crossing - 63°23.91'N, 145°44.85'W - This site is on the intersection of the Hines Creek Strand of the Denali Fault and the TAPS. This will place a spill very near Castner Creek draining Castner Glacier. From Castner Creek, it is about 0.8 mile to the Delta River. See Figure 2-94 for the location map and the exact spill site (+).

(2) SPECIFIC OIL TYPES

The award/contract gave general categories of oil types--crude and refined products (Tables 8-1 and 8-2).

More specific oil types were required for oil dispersion modelling and biological impact evaluations. MSNW selected the following representative oil types (properties are fully discussed in Section 5-E. Weathering). They are:

- Crude: Prudhoe Bay Crude
- Refined Products: Diesel-2
Gasoline (without additives)
- Residual Product: Bunker-C

These oil types were selected for two basic reasons:

1. They are probably the most common products that could be involved at most locations (assuming Prudhoe crude is similar to oil located in any future Bering Sea region development).
2. They are the products that have the largest data base on effects of oil either from accidental spills or laboratory experiments (bioassays).

(3) SEASONS

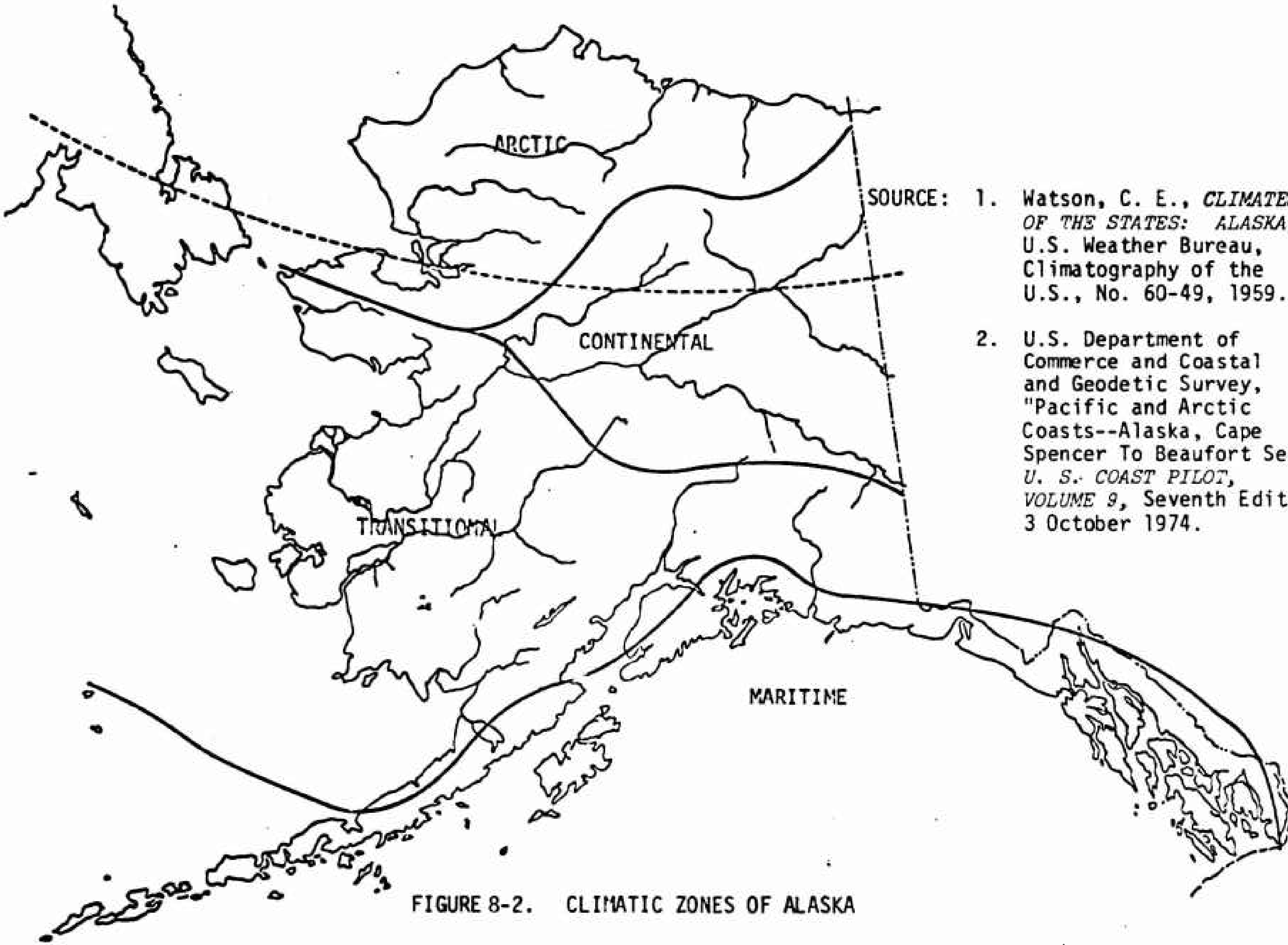
(a) GENERAL ALASKAN CLIMATOLOGY

The climate of Alaska has been characterized by four climatic zones.[4,5] These are the Maritime, Transitional, Continental, and Arctic zones illustrated in Figure 8-2. The zones were characterized according to the degree of maritime influence. General descriptions of the four climatic zones are given in Table 8-3.[4]

Alaska is surrounded on three sides by seas which influence the weather of the land masses. The seas exert a moderating influence. The influence of the Bering Sea and the Arctic Ocean is limited to periods of open water. The influence of these seas is negated when the sea is iced over.

Extension of the maritime influences to the interior is reduced by the St. Elias Mountains, the Chugach Mountains, the Kenai Mountains, the Aleutian Range, the Alaskan Range, the Kuskokwim Mountains, and the Brooks Range. Terrain also has a major effect on local variations in climate, especially on winds and precipitation. Channeling effects due to topographic features can result in greatly accelerated winds in localized areas. The *COAST PILOT* (V. 9)[6] noted that rugged terrain along the entire coast of the Gulf of Alaska makes for highly localized wind conditions.

The Gulf of Alaska and the Aleutian Island chain are areas of extensive cyclogenesis.[6,7] Primary cyclonic storm tracks parallel the Aleutian chain throughout the year. Secondary tracks are shown[7] through the Bering Sea and through the North Pacific and Gulf of Alaska. The high degree of storm activity results in strong winds all along the coast.



SOURCE: 1. Watson, C. E., *CLIMATES OF THE STATES: ALASKA*, U.S. Weather Bureau, Climatography of the U.S., No. 60-49, 1959.

2. U.S. Department of Commerce and Coastal and Geodetic Survey, "Pacific and Arctic Coasts--Alaska, Cape Spencer To Beaufort Sea," *U. S. COAST PILOT, VOLUME 9*, Seventh Edition, 3 October 1974.

FIGURE 8-2. CLIMATIC ZONES OF ALASKA

Average winds along the Aleutian chain are from 8 to 18 knots, with a general tendency toward the higher winds as one moves westward along the chain.[8]

TABLE 8-3. CLIMATIC ZONES OF ALASKA

MARITIME:	Dominated by maritime influences. Small temperature variations, high humidity, high precipitation and high cloud and fog frequencies. Little or no freezing weather. Mean annual temperature around 40°F.
TRANSITIONAL:	More pronounced temperature variations throughout the day and year, less cloudiness, lower precipitation and humidities. Mean annual temperature generally 25-35°F.
CONTINENTAL:	Dominated by continental climatic conditions. Great diurnal and annual temperature variations, low precipitation, low cloudiness and low humidity. Mean annual temperature 15-25°F.
ARCTIC:	Temperature variations lower than the continental, precipitation is extremely light and strong winds are not uncommon. Mean annual temperature 10-20°F. The Arctic climate is affected by marine influence in the Summer but not to any great extent in the Winter.

(b) TEMPERATURE AND ICE FREEZEUP/BREAKUP

Mean annual temperatures in Alaska vary from the low 40's in the Maritime Zone to about 10°F in the Arctic Zone.[6,7] The largest seasonal variations are found in the Continental Zone where Summer temperatures will reach average maximums in the upper 70's and Winter temperatures will fall to minus 40 to minus 50 degrees.[7]

Average dates of ice breakup in areas bordering the Gulf of Alaska vary from early April to late May.[6] Ice breakup varies from mid-April to early June in the Bering Sea, from early May to late May in the Yukon River, and from late May to late June in the Arctic Ocean.[6] Freezeup varies from early November to early December in the Gulf, from late October to early December in the Bering Sea, from late October to mid-November in the Yukon, and from early October to early November in the Arctic Ocean.[6]

(c) WINDS

Winds significantly affect the transport of oil slicks on water. Since the present study was concerned with estimating the effect of hypothetical oil spills at the various locations, the wind of importance is the predominant wind at each location. Accordingly, data were gathered to best estimate the predominant winds.

Surface weather observation summaries obtained from the National Climatic Center[9] were particularly useful. Examination of monthly averages showed evidence of seasonality of winds at the various locations. The number and duration of these seasons varied. All locations showed at least two major seasons corresponding to Summer and Winter. In general, the duration of Winter winds increased with increasing latitude, as expected. Spring and Fall were generally of shorter duration than Summer and Winter and, in some instances, could be described as short transition periods (e.g., Barter Island, King Salmon, Kotzebue, Umiat, and Yakutat). The climate of Cook Inlet has been described similarly[7] with Winter corresponding to the period from freezeup to breakup, Spring "immediately following the famed Alaska 'Break-up',"[7] and Summer comprising the period from June through early September. Thus, Fall and Spring comprise about one-third of the year, and Winter and Summer comprise the remaining two-thirds.

Figure 8-3 shows the directions of the predominant surface winds during Winter. Figure 8-4 shows predominant winds for Summer. Figures 8-5 and 8-6 are more detailed illustrations of predominant surface winds for Bristol Bay and Cook Inlet, respectively.

From information on winds, freezeup and breakup, and biological resources, it was apparent that all four seasons were of concern in and around Prince William Sound. All other sites appeared to be reasonaly characterized by ice/no ice (i.e., Winter (Summer) conditions).

C. CONTINUOUS/INSTANTANEOUS DISCHARGE CASES

Continuous and essentially instantaneous discharge modes are possible at all study spill sites. In this sense, "instantaneous" is defined to mean of short duration (i.e., less than one-half hour) in comparison with the total simulation time of the model (i.e., 72 hours). However, in reviewing the spectrum of possible cases, MSNW selected the instantaneous spill mode for all water-based sites as the most representative for the large volume spills (50,000 barrels). Such spills would most likely result from tanker accidents (collision, groundings, etc.), causing an almost instantaneous release. The scope of the study was not geared to catastrophic events wherein large amounts of oil are released to the environment, as in the case of major platform blowouts. The intermediate volume spills (10,000 barrels) most likely would result from barge accidents and the same rationale applies. Smaller volume (less than 10,000 barrels) spills may result from a wide variety of sources; however, since it is impossible to estimate flow rates for a wide variety of sources such as ballasting operations, terminal

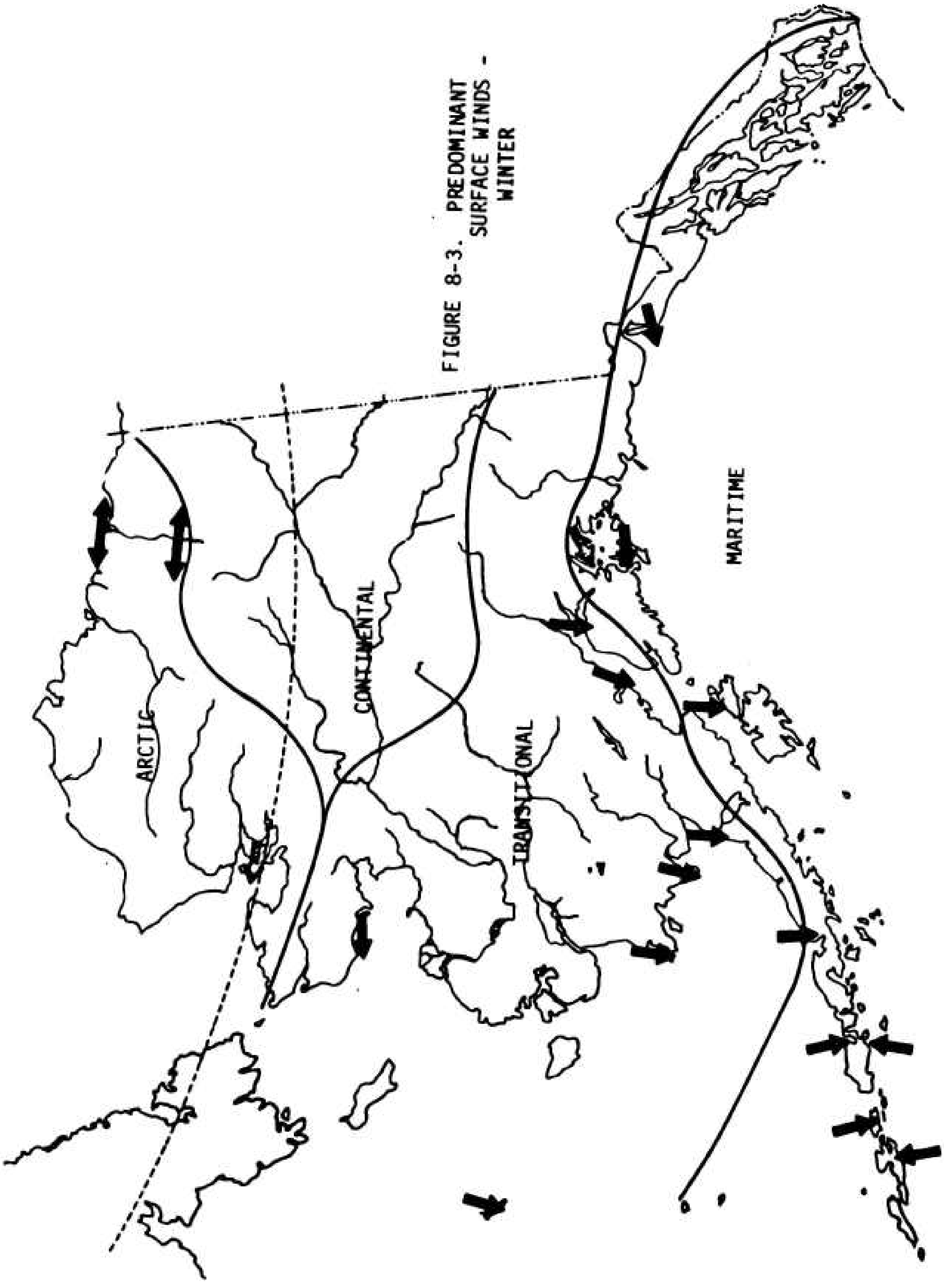


FIGURE 8-3. PREDOMINANT SURFACE WINDS - WINTER

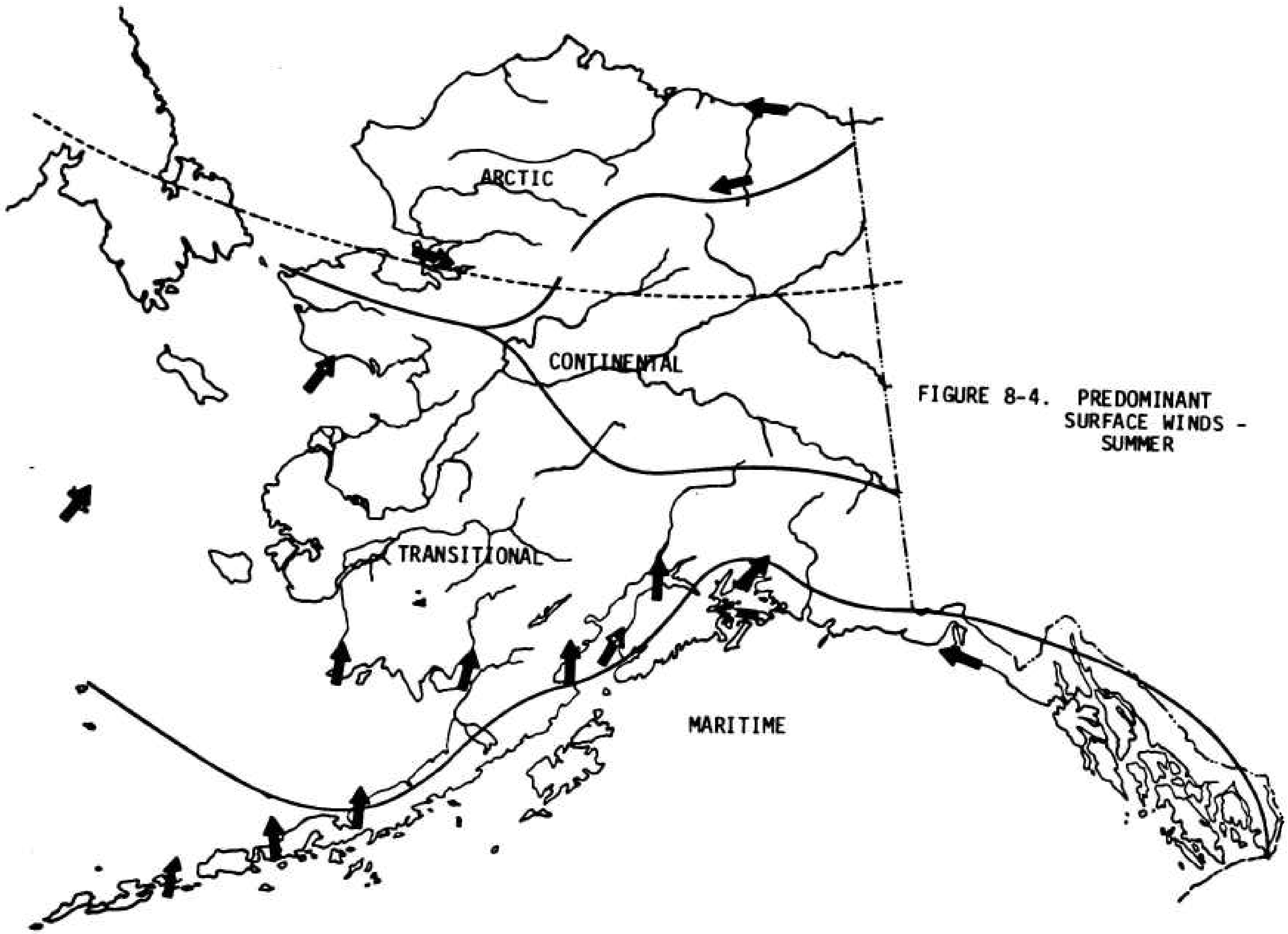


FIGURE 8-4. PREDOMINANT SURFACE WINDS - SUMMER

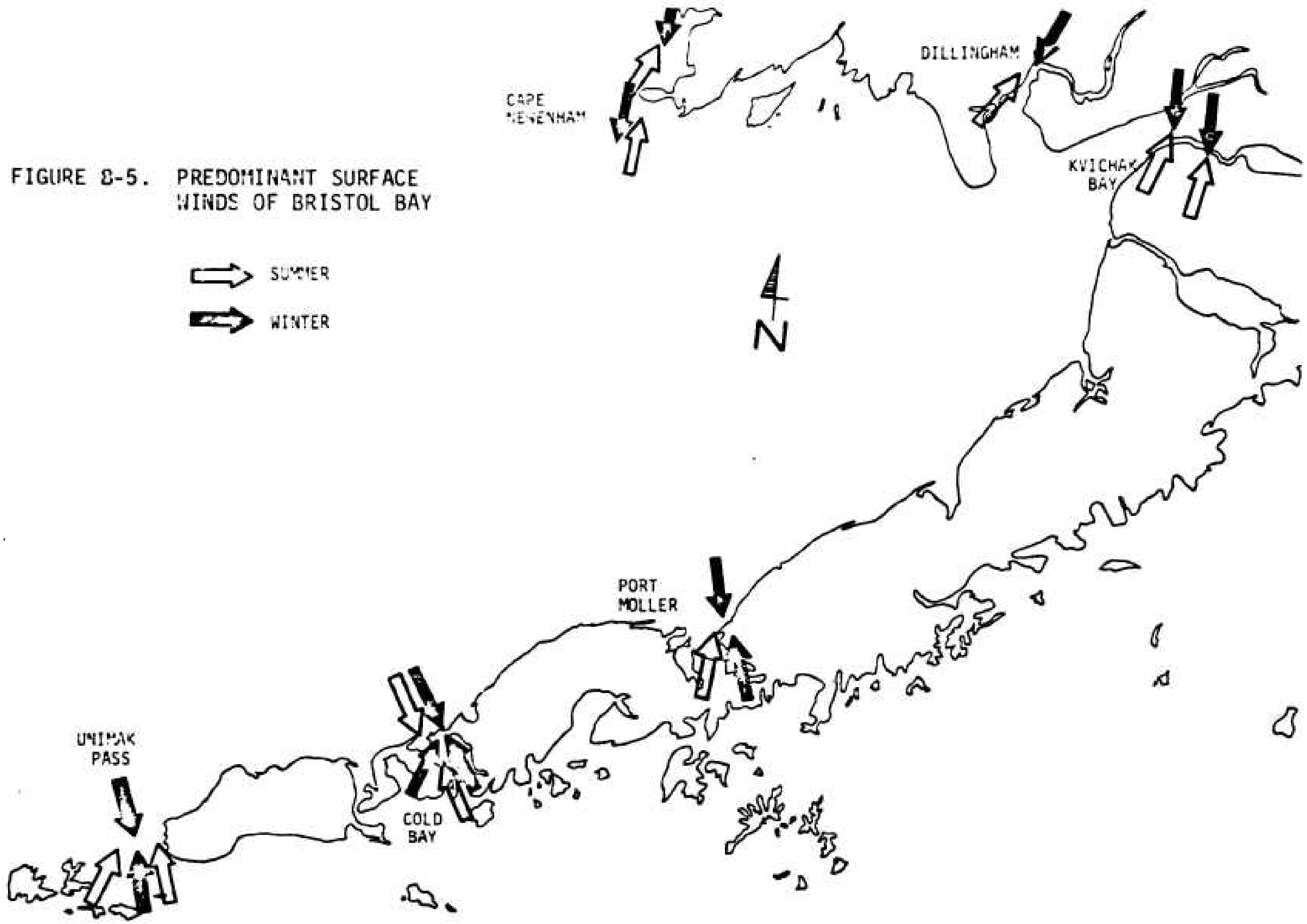


FIGURE 8-5. PREDOMINANT SURFACE WINDS OF BRISTOL BAY

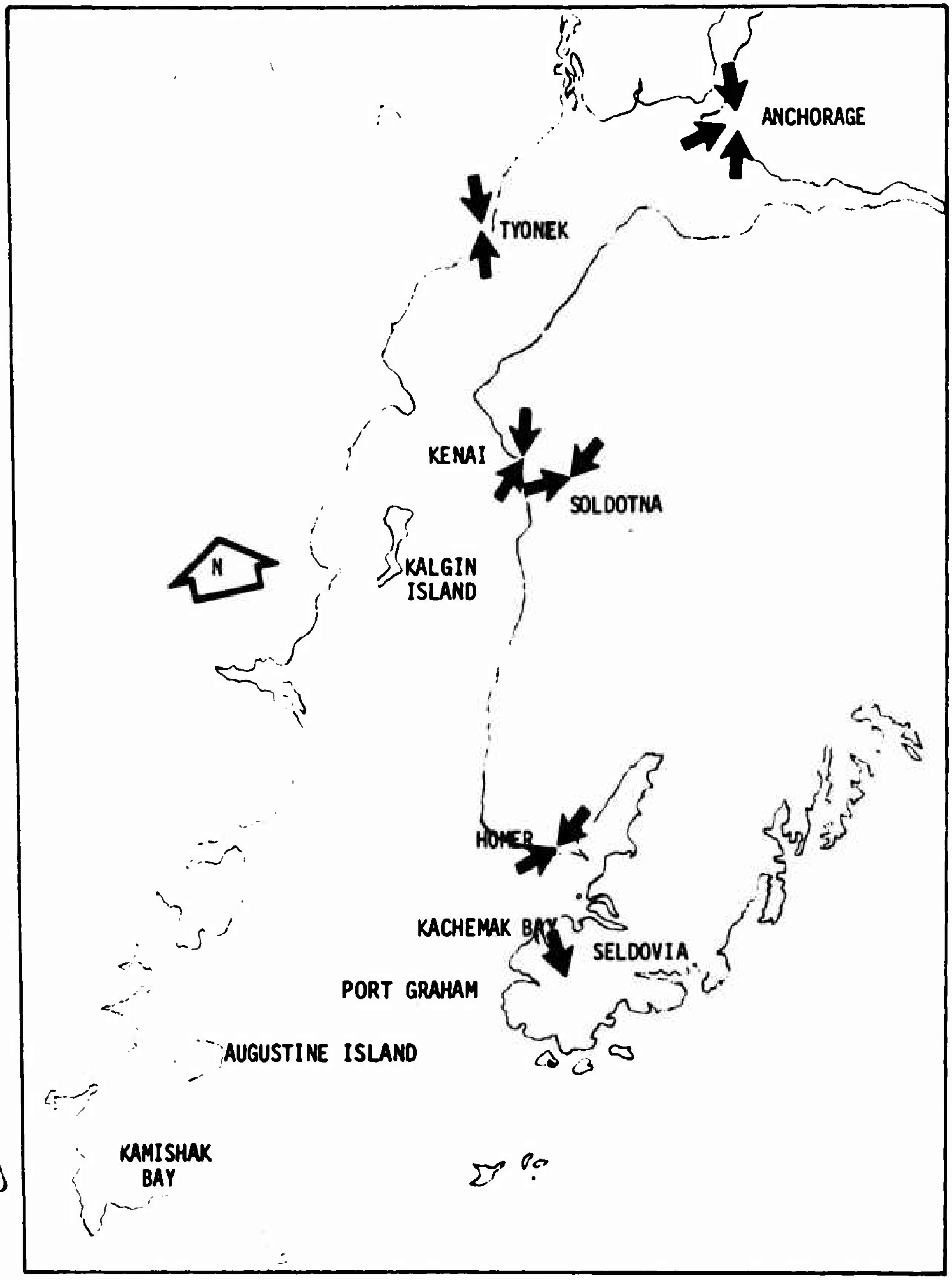


FIGURE 8-6. COOK INLET PREDOMINANT SURFACE WINDS

loading or offloading accidents, or small pipeline leaks, instantaneous release was again postulated.

For the major land-based pipeline sources, a continuous discharge mode was assumed with release times (roughly estimated from pipeline volume and flow rates) of from one-half to one hour duration. Such failure mode is more likely than an instantaneous discharge; slower leaks would in all likelihood be detected by the pipeline operator and action taken to restrict the flow of oil. MSNW noted that there exists a sensing threshold for detection of small flow rate leaks that may eventually release large amounts of oil. At the time, no definite information concerning the actual sensing threshold level was available.

D. OIL DISPERSION MODELLING CASES

Not all cases listed in Tables 8-1 and 8-2 can be quantitatively modelled within the present state-of-the-art. Current knowledge and analysis methods are discussed in detail in Section 5. The methodology used by MSNW for this study is briefly reviewed here.

(1) OPEN OCEAN WATERS

Open ocean cases (including all situations where the spill occurs in ice-free waters, whether offshore or in an estuarine area) were modelled using calm water physical spreading theory and wind/current driven dispersion theory (Section 5-A). No theory has been proposed to date to account for rough sea effects under stormy conditions. However, under stormy conditions, the probability of forming stable water-in-oil emulsions is enhanced, and the subsequent dispersion of these emulsions will be governed by wind and current transport. Thus, the use of the MSNW model to estimate the spill history under rough sea conditions is justified for determining the spill impact area.

(2) ICE-INFESTED WATERS

No adequate theory exists at the present time for modelling oil dispersion in ice-infested waters. Although calculation of oil spreading in ice pack leads may be performed (Section 4-C-1), the prediction of spill histories involves the ability to calculate the ice and/or ice-water mixture dynamics (Section 5-C). In order to estimate the spill impact area, MSNW utilized the theory for open-water dispersion in these cases. In support of this approach, it was noted that some evidence exists that ice is also transported at roughly 3 percent of surface wind speed and directly influenced by surface currents (Section 5-C-2). The effects of ice "pile-up" against shore or other congestion areas would reduce the areal impact of the spill, hence use of open-water dispersion analysis yields a conservative estimate of the impacted area.

(3) LAND/ICE CASES

The spreading of oil on land or ice is discussed in detail in Section 5-C. Land-based spills are directly influenced by slope, roughness, and porosity of the land and may be estimated for each specific case. Spills on ice are generally assumed to achieve a maximum terminal area (Section 5-C), and subsequent dispersion is governed by ice dynamics.

(4) RIVER CASES

When an oil spill reaches a flowing river, the subsequent dispersion is directly determined by river flow rate, width, and turbulence characteristics as determined by flow volume rate and gradient. Flow volume rate can be estimated for specific rivers for a given season and from topographical charts, the dispersion of the oil estimated. The effects of natural gathering areas along a given river, such as backwaters and eddies, cannot be estimated without detailed surveys of the specific rivers involved.

E. MATRIX EVALUATION

The matrix evaluation process to arrive at a relative ranking of impacts of spill cases was fully described in Chapter 7. The basic breakdown of the matrix evaluation process was:

- First, by location
- Second, by season
- Third, by oil product
- Fourth, by spill volume

The evaluation of the effect of spill mode was not directly addressed in the matrix evaluation. For the applicable spill modes for a specific location, season, oil product, and spill volume, MSNW brainstormed the problem to differentiate potential effects (physical, chemical, and biological) that the applicable spill modes could have on that given base case.

SECTION 8. REFERENCES

1. Request for Proposal No. CG-42, 913-A, U. S. Coast Guard, 12 March 1974.

2. U. S. Coast Guard Contract No. DOT-CG-42913-A, awarded 1 July 1974.

3. David S. Kaufman, Robert J. Williams, and Ben Hillikir, personal communication, August 19 and August 24, 1974.

4. Johnson, P. R. and C. W. Hartman, *ENVIRONMENTAL ATLAS OF ALASKA*, Institute of Arctic Environmental Engineering, University of Alaska, 1969.

5. Watson, C. E., *CLIMATES OF THE STATES: ALASKA*, U.S. Weather Bureau, Climatography of the U.S., No. 60-49, 1959.

6. U. S. Department of Commerce and Coastal and Geodetic Survey, "Pacific And Arctic Coasts--Alaska, Cape Spencer To Beaufort Sea, Seventh Edition," *U. S. COAST PILOT*, vol. 9, 3 October 1974.

7. Swift, W. H., R. E. Brown, L. V. Kinnel, M. M. Orgel, P. L. Petersen, and W. W. Waddell, *GEOGRAPHICAL ANALYSIS OF OIL SPILL POTENTIAL ASSOCIATED WITH ALASKAN OIL PRODUCTION AND TRANSPORTATION SYSTEMS*, U. S. Coast Guard Report CG-D-79-74, February 1974.

8. Wentink, Tunis, *WIND POWER POTENTIAL OF ALASKA: PART 1 - SURFACE WIND DATA FROM SPECIFIC COASTAL SITES*, Geophysical Institute, University of Alaska, UAG R-225.

9. National Climatic Center, *REVISED SUMMARY OF SURFACE WEATHER OBSERVATIONS, PART C - SURFACE WINDS*.

SECTION 9. CATALOG OF STUDY AREAS

A major effort of this research program was the assembly of physical and biological parameters that define the 17 study locations in Alaska. Time and budget constraints did not permit on-site visits of any of the 17 study locations, and the study team relied entirely on available literature, unpublished reports and manuscripts and personal communication with informed individuals or organizations.

A. GENERAL AREA DESCRIPTIONS

Each general location (17 total) required a specific group of physical and biological parameters. The sources for these data varied depending on who had conducted research into a given location's physical and biological environment. Data were not equally available for all locations. Generally speaking, the greatest amount of data exists for those locations close to man's present activities (either existant or proposed for the near future). A multitude of information exists for portions of the Cook Inlet area, whereas information is scarce for the more remote St. Matthew Island.

Where data were lacking, extrapolations were necessarily made from nearby locations. In the case of marine spills, all wind velocity and direction data had to come from a land-based station recording such information (i.e., air ports, weather stations). This required some adjustment to wind inputs over adjacent water spill sites. In other cases, some biological inputs came from the same location as the spill site and spill impact area. In both the physical and biological cataloging, extrapolation of data was the rule rather than the exception for most locations in this study. A positive aspect of this data extrapolation was the identification of major data gaps requiring future study (see Section 10).

(1) PHYSICAL PARAMETERS

The primary physical parameters researched for this study included wind direction and velocity, current direction and velocity, temperature (water on marine temperatures, air and river water temperatures on terrestrial spills), topography, shorelines, and bathymetry.

(a) WIND

At all the marine sites where oil dispersion modelling was completed, predominant wind direction and velocity input were required. This information was gathered for numerous sources and is summarized in Table 9-1. At no location in this study was wind input data site specific. Wind direction and velocity were necessarily extrapolated from land-based sources (airports, weather stations) to the "over-water" site chosen as the exact spill site. See the wind data summary Tables in Appendix D.

(b) CURRENTS

At all marine locations, another input to the oil dispersion model was surface sea currents. The two primary sources of information were the *TIDAL CURRENT TABLES 1974*[1] and the *U. S. COAST PILOT NO. 9*.[2] These two sources generally provided some working knowledge of surface tidal currents at all locations. As expected, the amount of information available generally declines as one moves further north in the Bering Sea and into the Chukchi and Beaufort Seas.

TABLE 9-1. SURFACE WIND DATA BASE.

DATA TYPE (1)	AREA OR LOCATION (2)	PERIOD (3)	DATA SOURCE (4)
Climatic Conditions, and Predominant surface winds-general summary	Cook Inlet North Slope Gulf of Alaska Bristol Bay Kuskokwim-Bering Sea Norton Sound Kotzebue Sound- Chuckci Sea Pipeline Route	not stated	1
General Climate and Predominant Winds	Gulf of Alaska Bering Sea Arctic Ocean	variable	2
Climatological Tables	Yakutat Cordova Anchorage Cold Bay King Salmon Nome Kotzebue Barter Island	variable	2
Surface Wind - Transition matrix and mean speads	Yakutat	not stated	3
Climate and Surface winds	Valdez	1963-1967	4
General Climate and Predominant Winds	Kotzebue	not stated	5
General Climate and Predominant Winds	Cook Inlet	variable	6
Surface Winds	Cold Bay	1955-1969	7
Surface Wind Observations	Anchorage Barter Island Cold Bay Soldotna Kenai	1941-1968 1947-1970 1942-1968 1962-1964 1948-1967	8

TABLE 9-1. (CONT'D.)

DATA TYPE (1)	AREA OR LOCATION (2)	PERIOD (3)	DATA SOURCE (4)
Surface Wind Observations (cont'd)	Homer	1939-1941	8
	Cordova	1946-1970	
	Driftwood Bay	1959-1969	
	Kotzebue	1945-1970	
	King Salmon	1942-1970	
	Naknek	1942-1964	
	Nome	1949-1970	
	Port Moller	1959-1969	
	Umiat	1946-1955	
	Yakutat	1941-1971	
	St. Matthew Island	1942-1945	
	Valdez	1963-1967	

---

1. Swift, W. H., R. E. Brown, L.V. Kinnel, M. M. Orgel, P. L. Petersen, W. W. Waddell, *GEOGRAPHICAL ANALYSIS OF OIL SPILL POTENTIAL ASSOCIATED WITH ALASKAN OIL PRODUCTION AND TRANSPORTATION SYSTEMS*, Pacific Northwest Laboratory, Division of Memorial Institute to the United States Coast Guard, USCG Report CG-D-79-74, February 1974.

2. U.S. Department of Commerce and Coastal and Geodetic Survey, *PACIFIC AND ARCTIC COASTS - ALASKA, CAPE SPENCER TO BEAUFORT SEA*, Seventh Edition (October 3, 1974), U.S. Coast Pilot Volume 9.

3. Massachusetts Institute of Technology, *PRIMARY, PHYSICAL IMPACTS OF OFFSHORE PETROLEUM DEVELOPMENTS*, report to the Council on Environmental Quality, MITSG 74-20, April 1974.

4. Alyeska Pipeline Servia Co., *402 METEOROLOGY*, Oil Spill Contingency Plan, Alyeska Marine Terminal, Vol 1 - The Plan, Vol 2 - Annexe, Woodward - Envicon Inc., Environmental Consultants

5. Alaska Planning Group, *ENVIRONMENTAL STATEMENT-PROPOSED CAPE KRUSENSTERN NATIONAL MONUMENT, ALASKA*, National Park Service, U.S. Department of the Interior, DES 73 87, December 1973, Draft.

6. Alaska University, *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U.S. Department of Commerce, COM-73-10337, August 1972.

7. Wentunk, Tunis, Jr., *WIND POWER POTENTIAL OF ALASKA, PART I: SURFACE WIND DATA FROM SPECIFIC COASTAL STIES*, University of Alaska, Geophysical Institute, Report UAG-R-225.

8. National Climatic Center, revised summary of Surface Weather Observations, Part C, Surface Winds.

Additional sources included location specific investigations of most of these marine sites. Studies included reports on OCS development,[3] Valdez Harbor and vicinity,[4-7] Cook Inlet,[8] Western Gulf of Alaska,[9] Bristol Bay Environment,[10] Bering Sea,[3] Kotzebue vicinity,[11] and the Alaskan Arctic Coast.[12]

The available marine surface current data were quite general and required a good deal of extrapolation and interpolation for utilization in the tidal current polygons prepared for oil dispersion modelling. See Section 5-B-1 and Appendix D for tidal current interpretation examples. This intrepretation of surface tidal current is believed to be a moderate source for error, particularly for sites beyond Prince William Sound and Cook Inlet.

Mathematical Sciences Northwest, Inc., was made aware of research in progress that will greatly advance the marine tidal current information for Cook Inlet. National Ocean Survey (NOS) of NOAA conducted tide and tidal current studies in lower Cook Inlet and middle Cook Inlet in the Summer of 1973 and 1974.[13] Upper Cook Inlet is scheduled for study in the Summer of 1975 and possibly Prince William Sound for the Summer of 1976.[13] The problem with the data collected from the two lower parts of Cook Inlet is that the information obtained from NOS is raw data that has received little or no evaluation. It is beyond the scope of this study to analyze and then utilize these data. However, this information should be factored into the future evaluations conducted on oil spill dispersion and impacts as the data becomes available in usable form.

Information on river currents was also required for the four land oil spills (Onshore Prudhoe, Umiat, Yukon River Crossing, and Denali Fault Crossing) as each case involves a brief land encounter followed by contact with the Sagavanirktok, Colville, Yukon, and Delta rivers, respectively. Information sources were scarce but sufficient for study requirements.[7,9,12,14-16] See the additional discussion of surface current interpretation in Section 4.

(c) TEMPERATURE

Marine sites and land sites required temperature and temperature-related information (freezeup, breakup of ice) to properly determine oil dispersion and movement. This information was generally obtained from the *COAST PILOT*[6] and from National Climatic Center data.[17] Useful information on snow cover and air temperatures along the Trans-Alaska Pipeline (reports DM-CDB-010 and DM-CDB-015) were reviewed in Alyeska's Anchorage office in August 1974. These reports are not released to the public and were not available to MSNW. The Coast Guard should be aware of reports like these as they would be of great logistic value for pipeline-related locations when they do become available to the public.

Additional temperature information was obtained from several location-specific reports as indicated for surface current data.

(d) TOPOGRAPHY, SHORELINES, BATHYMETRY

Land and marine locations required information on terrestrial topography both for the evaluation of oil dispersion and movement and biological cataloging. U.S. Gelogical Survey quadrangle maps were utilized in one per 250,000 scale for the shoreline mapping of all marine shorelines within the 50-km^2 grid utilized in displaying oil dispersion model results. Coast and Geodetic Navigational Charts were not utilized because these charts have varying scales among the 13 marine locations which present an additional complication to the oil dispersion modelling process.

The locations on land (Onshore Prudhoe, Umiat, Yukon River Crossing, and Denali Fault Crossing) required more detail as to land slopes for land spills and hydrographic heads for river spills so that U.S. Geological Survey Quadrangle Maps in 1: 63,360 scale were used. MSNW also utilized information in charts provided by Alyeska Pipeline Service Company.[15,16,18,19]

General coastline topography was also integrated from U.S. Geological Survey Quadrangles for the extrapolation of land-source wind direction and velocity data to actual spill sites over water.

Shoreline information (physical types) were taken from U.S. Geological Quadrangles and Coast and Geodetic Survey charts and information in general location specific reports as utilized for the surface current data base. The prior experience of several MSNW employees and consultants was also used in those locations in Alaska that these individuals have visited in the past.

Bathymetry for the locations came primarly from U.S. Geological Survey Quadrangles and Coast and Geodetic Survey charts.

(2) BIOLOGICAL RESOURCES

Unlike the physical parameters above, several hundred reports and manuscripts were researched to prepare the environmental evaluation matrix. To begin this task of biological resource cataloging of most of Alaska, MSNW obtained consultants with specific biological areas of interest. These included:

- Dr. Albert W. Erickson, University of Washington, Wildlife Biology.

- Dr. Phillip A. Lebednik, University of Washington,* Botany.
- Mr. Edgar A. Best, International Pacific Halibut Commission, Marine Fisheries.
- Mr. Larry G. Gilbertson, University of Washington,** Salmon Fisheries.
- Mr. Charles A. Simenstad, University of Washington, Invertebrates and Oil Effects.
- Dr. Rita Horner, formerly with the University of Alaska, Institute of Marine Science, Arctic Coast Biology.

These individuals provided MSNW with summary resource catalogs with supporting literature. This information was then compiled by MSNW into location-specific evaluation matrices by season. These matrices incorporated the information on relative abundance and relative commercial, recreational, subsistence, and ecological importance for each location (see matrix discussion in Section 6). These matrix imputs were then reviewed several times by MSNW and its consultants (see discussion of Modified Delphi Process in Section 7).

It is not practical to list here all of the numerous data sources obtained from the literature for this biological cataloging effort. MSNW initially relied on the "compendium" type reports for the Gulf of Alaska,[20, 21, 26, 27] Western Gulf Alaska,[9] Valdez Harbor and vicinity,[4, 5, 7, 21-25] Cook Inlet, Bristol Bay Environment,[3, 10] Kotzebue vicinity,[11] Arctic Coast,[12] and the Pipeline Route.[28-30] From these summary reports, the search was expanded to additional references.

---

*Now with the University of British Columbia, Vancouver, B.C.

**Now with the Quinault Indian Tribe Fisheries Program, Tahola, Washington.

The marine flora of the 14 coastal locations presented a special problem with regard to cataloging the marine plants which occur there. At all of these locations it is assumed that the oil spill enters or reaches the surface of the sea and that oil is not physically transported beyond the level of extreme high tides or, in highly exposed* areas, the level of highest splash from wave action. Therefore, true terrestrial vegetation is assumed to be not affected directly by oil spills and is excluded from this discussion. Terrestrial vegetation for the four terrestrial sites was obtained from Alyeska and other sources.

Six major categories of marine flora can be recognized at the 14 Alaskan marine locations:

(1) strand or beach vegetation

(2) intertidal** seaweeds

(3) eelgrass (*Zostera marina*) beds

(4) subtidal*** seaweeds

(5) the floating portions of subtidal seaweeds (floating kelp beds)

(6) phytoplankton

---

*Exposed = exposed to heavy wave action (opposite of protected).

**Intertidal = between the extreme limits of the tides in any one place.

***Subtidal = below the intertidal.

There is no mention in the literature of the presence of true salt marshes such as occur on the East Coast of the United States and in Alaska.[31-37] Salt marshes may occur in Alaska, particularly east of the Alaska Peninsula. True salt marshes have a flora composed mainly of grasses and sedges and occur within the intertidal region. In Alaska, these types of vegetation are reported to occur in estuarine localities and lagoons.[32, 35, 36] Because most of these habitats are beyond the reach of marine oil spills (Cook Inlet is an exception which is discussed below), they are not included in the present discussion.

There is a little specific information on the coastal vegetation of Alaska. This is particularly true of the coastline west and north of Cook Inlet. At most sites, there have never been any biological investigations of pertinence to this project. It is necessary to outline the available knowledge from all of Alaska, establish generalized areas of similar flora (such as Arctic, boreal, etc.) and habitat types (exposed, protected, rocky, sandy, etc.), and then use these generalizations to establish the theoretical vegetation at any particular marine location.

There is even less information available on the "importance" of species or groups of species in ecosystem stability or foodchains. As a result, it is impossible to establish whether some species should be given more weight than others in evaluating the distribution of the flora at specific locations. As a consequence, the species have here been grouped into broad categories based on general ecological divisions and the expected effects of oil spills, e.g., the floating portions of subtidal seaweeds are in a separate category from the holdfasts of the same plants because the contact and presumably the effects of an oil spill would be totally different in each case.

A method was developed to estimate the relative abundances of the various categories of flora at any one location. The type of substrate along the coastline was determined from geological papers, geological maps, and coast and geodetic survey charts.[38-45] Segments of shoreline were categorized into one of the following:

1. rock
2. cobble/gravel
3. sand
4. mud

This information was "digitized" on computer tape for all shorelines within a 50-km square area (2,500 sq. km) of the spill site. Sums of the absolute lengths in meters and the percentages of each type were calculated for each location.

The theoretical relative abundance of each vegetation type was estimated as follows:

STRAND - strand vegetation was assumed to occur on all mud and sand shores and to have one-half the abundance along a gravel shore; it was assumed to be absent on rock shores and on all other shores in the Winter (most strand plants are annuals[47]).

INTERTIDAL SEAWEEDS - Assumed to be present on all rock shores and one-half the abundance on cobble/gravel shores in Summer. In Winter, rock shores were assumed to one-half the abundance in Summer and to be absent on gravel.

EELGRASS - eelgrass abundance estimates based on substrate alone were considered very accurate and, for the most part, this was estimated using data from the literature on eelgrass bed locations.

TABLE 9-2. SEASONAL ESTIMATORS OF ABUNDANCE OF FLORAL CATEGORIES BASED ON TOTAL LENGTH OF SHORELINE SUBSTRATE TYPE

SUBSTRATE TYPE (1)	FLORA CATEGORY (2)	SUMMER FACTOR (3)	WINTER FACTOR (4)
Rock	Intertidal Seaweeds	x 1.0	x 0.50
	Subtidal Seaweeds	x 1.0	x 0.50
	Floating Seaweeds	x 1.0	x 0.00
Cobble/Gravel	Strand Seaweeds	x 0.5	x 0.00
	Intertidal Seaweeds	x 0.5	x 0.00
	Subtidal Seaweeds	x 0.5	x 0.25
Sand	Strand Seaweeds	x 1.0	x 0.00
Mud	Strand Seaweeds	x 1.0	x 0.00

SUBTIDAL SEAWEEDS - the relative amount of subtidal area is not correlated well with the amount of coastline. Nevertheless, the coastline values were used to estimate subtidal abundances for lack of a better estimator. Subtidal seaweeds were assumed to be present on all rock bottoms and one-half as abundant on cobble/gravel bottoms. In the Winter, it was assumed that the vegetation was reduced by one-half.

FLOATING SEAWEEDS - as with eelgrass beds, it was difficult to estimate the occurence of these based on substrate alone. According to Druehl[46], this type does not occur north of the Alaska Peninsula. Within the limits of geographical distribution, it was assumed that floating seaweeds occurred on rock bottoms only in the Summer.

A summary of the calculations used to estimate the abundance of the various categories of flora based on substrate abundance is given in Table 9-2.

Many species are reported in the marine flora of Alaska, but the presentation of a species list does not provide much information about the effects which might result from an oil spill. Therefore, a general description of the flora categories will be presented in which only the more abundant species, those which are thought to be more severly affected by oil, or which are known to be important in other respects, will be mentioned. Lists of species can be obtained from the literature cited.

(a) DISTRIBUTION OF STRAND VEGETATION IN ALASKA

Breckon and Barbour[47] have presented a recent review of the strand vegetation of the Pacific North American Coast, including Alaska. Strand vegetation is composed of vascular (flowering) plants which occur above the intertidal region on sandy and gravelly substrates where salt spray from the ocean affects the composition of the flora. Most strand species are obligate or facultative halopytes (halopytes--able to tolerate salty soil and/or salt spray).[47]

The strand environment is very unstable, particularly on the north and west coasts of Alaska where extensive Winter ice scouring destroys most or all of the plants which become established during the Summer months.[32,36,40] Thus, all of these plants are Summer annuals. Almost all of the species of strand vegetation in Alaska have circumarctic or Beringian-Eastern North American distributions, with only a few species which can be characterized as temperate beach, Beringian, or introduced. A list of the first two types is given in Table 9-3.

Associated with the biological resource cataloging was a literature search to gather data on the impact of oil spills on the flora/fauna and natural processes involved at the study location. Again, the number of specific references is large and cannot simply be summarized here (see list of references in Section 4).

TABLE 9-3. STRAND VEGETATION SPECIES IN ALASKA, ACCORDING TO GEOGRAPHICAL RANGE (NORTHERN LIMIT INDICATED IN (): Y = YAKUTAT, K = KOTZEBUE)

CIRCUMARCTIC (1)	BERINGIAN-EASTERN NORTH AMERICAN (2)
Festuca rubra (Y)	*Angleical lucida (K)*
Honobenya peplodies	*Conioselinum chinense (K)*
Lathrymus japonicus	*Elymus mollis*
Lingusticum scoticum (K)	*Poa eminens (K)*
Mertensia maritima	*Senscio pseudo-arnica (K)*

B. SOURCES

As noted, this was a literature study rather than a field study--no Alaska field investigations were made by the research team. Several team members had previously visited most of the 17 locations in this study.

In addition to researching the available literature, MSNW visited with individuals having special knowledge of the study areas both locally and in Alaska. A summary of these source agencies and their locations follows:

Alyeska Pipeline Service Company, Anchorage, Alaska
U.S.D.I., Bureau of Land Management, OCS, Anchorage, Alaska
Arctic Environmental Information and Data Center, Anchorage, Alaska
U.S.D.I., Alaska Pipeline Office, Anchorage, Alaska
U.S.D.I., Sport Fish and Wildlife Service, Anchorage, Alaska
U.S.D.I., National Park Service, Anchorage, Alaska
U.S.D.I., Bureau of Outdoor Recreation, Anchorage, Alaska
U.S. Army, Corps of Engineers, Anchorage, Alaska
Environmental Protection Agency, Anchorage, Fairbanks, Alaska
Alaska Department of Fish and Game, Anchorage, Fairbanks, Juneau, Alaska
University of Alaska, Fairbanks, Alaska
- Institute of Marine Sciences
- Geophysical Institute
- Tundra Biome Center

NOAA, National Marine Fisheries Service, Juneau, Alaska and Seattle, Washington
U.S.D.I., Forest Service, Juneau, Alaska
U.S. Coast Guard Environmental Branch, Juneau, Alaska
Alaska Department of Environmental Conservation, Juneau, Alaska
University of Calgary, Environmental Sciences Center, Calgary, Alberta
Shell Oil Company, Environmental Conservation Department, Houston Texas
Alaska Department of Natural Resources, Anchorage, Alaska
Texas A&M, Department of Environmental Engineering, College, Station, Texas

Appendices A - D present the physical and biological resource data utilized in this study. Section 2 provides summarized resource data on a location basis.

SECTION 9. REFERENCES

1. U.S. Department of Commerce, *PACIFIC COAST OF NORTH AMERICAN AND ASIA, TIDAL CURRENT TABLES 1974*, National Oceanic and Atmospheric Administration, National Ocean Survey.

2. U.S. Department of Commerce and Coastal and Geodetic Survey, "Pacific And Arctic Coasts - Alaska, Cape Spencer To Beaufort Sea," *U.S. COAST PILOT, VOLUME 9*, Seventh Edition, 3 October 1974.

3. Hood, D. W. and E. J. Kelley, *OCEANOGRAPHY OF THE BERING SEA--WITH EMPHASIS ON RENEWABLE RESOURCES*, Institute of Marine Science, University of Alaska, Occasional Publication No. 2, 1974.

4. Institute of Marine Science, *ENVIRONMENTAL STUDIES OF PORT VALDEZ*, ed. by Hood, D. W., W. E. Shiels, and E. J. Kelsy, University of Alaska, Occasional Publication 3, July 1973.

5. Institute of Marine Science, *ENVIRONMENTAL STUDIES OF PORT VALDEZ, DATA VOLUME I*, ed. by Hood, D. W., W. E. Shiels, and E. J, Kelsy, University of Alaska, Occasional Publication 3A, July 1973.

6. Alyeska Pipeline Servia Co., *403 OCEANOGRAPHY*, Oil Spill Contingency Plan, Alyeska Marine Terminal, Vol 1 - The Plan, Vol 2 - Annexe, Woodward - Envicon Inc., Environmental Consultants.

7. United States Department of the Interior, *ENVIRONMENTAL IMPACT STATEMENT-PROPOSED TRANS-ALASKA PIPELINE, VOLUMES I - VI*, Stock Number 2401-2116, 1972.

8. Alyaska University, *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U.S. Department of Commerce, COM-73-10337, August 1972.

9. Arctic Environmental Information and Data Center, *WESTERN GULF OF ALASKA, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, Bureau of Land Management - Offshore Continental Shelf Office.

10. Arctic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, Department of the Army, Alaska District, Corps of Engineers, February 1974.

11. Wilimovsky, Norman J. (editor) and John N. Wolfe (associate editor), *ENVIRONMENT OF THE CAPE THOMPSON REGION, ALASKA*, Atomic Energy Commission, Report PNE-481, 1966.

12. The Arctic Institute of North American, *THE ALASKAN ARCTIC COAST - BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, Contract No. DACW85-74-C-0029, June 1974.

13. Lt. Cmdr. Carl W. Fisher, Chief Ocean Division, National Ocean Survey, personal communication, 26 September 1974.

14. Greenwood, Julian K. and R. Sage Murphy, *FACTORS AFFECTING WATER MANAGEMENT ON THE NORTH SLOPE OF ALASKA*, Institute of Water Resources in cooperation with the Sea Grant Program, University of Alaska, Report No. IWR 19, Sea Grant Report No. 72-3, February 1972.

15. Alyeska Pipeline Service Company, *TRANS ALASKA PIPELINE SYSTEM DRAINAGE STUDY, YUKON RIVER TO PRUDHOE BAY, SAGAVANIRKTOK RIVER BASIN*, Map 19.

16. Alyeska Pipeline Service Company, *TRANS ALASKA PIPELINE SYSTEM DRAINAGE STUDY, YUKON RIVER TO PRUDHOE BAY, PUTULIGAYUK RIVER BASIN*, Map 20.

17. National Climatic Center, revised summary of Surface Weather Observations, Part C, Surface Winds.

18. Alyeska Pipeline Service Company, *TRANS ALASKA PIPELINE SYSTEM DRAINAGE STUDY, YUKON RIVER TO PRUDHOE BAY, YUKON RIVER BASIN, YUKON RIVER SECTION*, Map 1.

19. Alyeska Pipeline Service Company, *TRANS ALASKA PIPELINE SYSTEM DRAINAGE STUDY, VALDEZ TO YUKON RIVER, TANANA RIVER BASIN, DELTA RIVER SECTION*, Map 6.

20. Massachusetts Institute of Technology, *PRIMARY, PHYSICAL IMPACTS OF OFFSHORE PETROLEUM DEVELOPMENTS*, Council On Environmental Quality, MITSG 74-20, April 1974.

21. Rosenberg, Donald H. (editor), *A REVIEW OF THE OCEANOGRAPHY AND RENEWABLE RESOURCES OF THE NORTHERN GULF OF ALASKA*, Institute of Marine Science, University of Alaska, IMS Report R72-23, Sea Grant Report 73-3, February 1972.

22. Noerenberg, Wallace H., *FISH AND WILDLIFE INFORMATION AND RECOMMENDATIONS, TRANS ALASKA PIPELINE, JULY 20, 1974*, Fish and Wildlife Consultant, Appendix E-3, 1025.

23. Alyeska Pipeline Servia Co., *401 BIOLOGICAL*, Oil Spill Contingency Plan, Alyeska Marine Terminal, Vol 1 - The Plan, Vol 2 - Annexe, Woodward - Envicon Inc., Environmental Consultants.

24. Myren, Richard T., *EVALUATION OF THE MARINE FISHERY RESOURCES OF PRINCE WILLIAM SOUND AND COPPER AND BERING RIVERS WITH RESPECT TO THE POTENTIAL EFFECT OF THE PIPELINE TERMINUS AT VALDEZ, ALASKA*, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Biological Laboratory, Auke Bay, Alaska, MR-F No. 86, April 1971.

25. National Academy of Sciences, *THE GREAT ALASKA EARTHQUAKE OF 1964, BIOLOGY*, Committee on the Alaskan Earthquake of the Division of Earth Sciences, National Research Council, Washington, D. C., ISBN 0-309-01604-5, 1971.

26. Alaska University, *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U.S. Department of Commerce, COM-73-10337, August 1972.

27. Alaska District, Corps of Engineers, *ENVIRONMENTAL IMPACT STATEMENT--OFFSHORE OIL AND GAS DEVELOPMENT IN COOK INLET, ALASKA*, No. 239, April 1974.

28. Alyeska Pipeline Service Company, *BIOLOGICAL DOCUMENTATION OF THE TRANS ALASKA PIPELINE SYSTEM*, Summary Report, Appendix E-3.1014, April 1974.

29. Bureau of Land Management, *ENVIRONMENTAL ASSESSMENT ATLAS, PROPOSED TRANS-ALASKA PIPELINE SYSTEM*, Alaska State Office, Division of Pipeline, July 1973.

30. United States Department of the Interior, *ENVIRONMENTAL IMPACT STATEMENT-PROPOSED TRANS-ALASKA PIPELINE, VOLUMES I - VI*, Stock Number 2401-2116, 1972. Final.

31. Hulten, E., *FLORA OF ALASKA AND NEIGHBORING TERRITORIES*, Stanford University Press, 1008 pages, 1968.

32. Hanson, H. C., "Characteristics Of Some Grassland, Marsh, And Other Plant Communities In Western Alaska," *ECOL. MONOGR.*, 21:317-378, 1951.

33. Hulten, E., "Contribution To The Knowledge Of Flora And Vegetation Of The Southwestern Alaskan Mainland," *SVENSK BOT. TIDSSKR.*, 60(1): 175-189, 1966.

34. Johnson, A. W., L. Viereck, R. Johnson and H. Melchior, *CHAPTER 14. VEGETATION AND FLORA*, in: Willimovsky, N. and J. Wolfe (eds.), "Environment Of the Cape Thompson Region, Alaska, U.S.A.E.C., 1966.

35. Stair, L. D. and F. Pennell, "A Collection Of Plants From Yakutat, Alaska," *BARTONIA*, 24:9-21, 1946.

36. Hanson, H. W., "Vegetation Types In Northwestern Alaska And Comparison With Communities In Other Arctic Regions," *ECOLOGY*, 34(1): 111-140, 1953.

37. Wiggins, J. L. and F. Thomas, *A FLORA OF THE ALASKAN ARCTIC SLOPE,* University of Toronto Press, 1962.

38. Burk, C. A., *GEOLOGICAL MAP OF THE ALASKA PENINSULA, SOUTHWEST SIDE OF WIDE BAY*, U. S. Geological Survey, Map, 1965.

39. Mendenhal, W. C., *RECONNAISSANCE FROM FORTH HAMLIN TO KOTZEBUE SOUND, ALASKA*, U.S. Geological Survey Proth. Paper 10, 1902.

40. Schrader, F. C., *A RECONNAISSANCE IN NORTHERN ALASKA*, U.S. Geological Survey Prot. Paper 20, 139 paper, figs 1-4, pls. I-XVI, 1904.

41. Hartwell, A. D., "Classification And Relief Characteristics Of Northern Alaska's Coastal Zone," *ARCTIC*, 244-252, 1973.

42. Mendenhall, W. C., *A RECONNAISSANCE IN THE NORTON BAY REGION, ALASKA IN 1900,* in: "Reconnaissance In The Cape Nome And Norton Bay Regions, Alaska, In 1900," U.S. Geological Survey, Government Printing Office, Washington, D.C., pp. 181-218, 1901.

43. Brooks, A. H., *A RECONNAISSANCE OF THE CAPE NOME AND ADJACENT GOLD FIELDS OF SEWARD PENINSULA ALASKA, IN 1900,* in: "Reconnaissance In The Cape Nome And Norton Bay Regions, Alaska, In 1900," U.S. Geological Survey, Government Printing Office, 1901.

44. Tarr, R. S., *THE YAKUTAT BAY REGION, ALASKA - PHYSIOGRAPHY AND GLACIAL GEOLOGY*, U. S. Geological Survey Prof. Paper 64, 183 pages, 1909.

45. Collier, A. J., *A RECONNAISSANCE OF THE NORTHWESTERN PORTION OF SEWARD PENINSULA, ALASKA*, U.S. Geological Survey Prof. Paper 2, 1902.

46. Druehl, L. D., "The Pattern of Laminariales Distribution In The Northeast Pacific," *PHYCOLOGIA*, 9(3/4):237-247, 1970.

47. Breckon, G. and M. Barbour, "Review Of North American Pacific Coast Beach Vegetation," *MADRONO*, 22(7):333-359, 1924.

SECTION 10. FUTURE STUDIES

Recognizing the pioneering nature of this study, the U.S. Coast Guard directed MSNW to identify data gaps and recommend further studies that are needed to reduce such gaps and improve the methodology. This Section provides such information grouped under four headings: Biological Data, Physical Data, Oil Cleanup, and Containment and Spill Response Readiness.

A. BIOLOGICAL DATA

Clearly absent from the literature are comprehensive descriptions of biological species and their abundance at many of the sites of interest to this study. This information is needed if one is to more accurately estimate the consequences of a spill in advance and portray a baseline against which post-spill conditions can be compared. The relation of particular species to the overall food web is also important in this regard. Population and repopulation dynamics for various species, if known, would have been of great assistance to the project investigators in assessing the long-term impact of spills. This latter information would also be useful in weighing the value of implementing cleanup measures following a spill. The task of the project investigators would have been greatly simplified had there been some understanding of the economic value of different species as well. Finally, the short-term and chronic (long-term) effect of low level concentrations of oil on flora and fauna requires better understanding.

It is recommended that investigations to characterize species diversity and abundance at locations that are susceptible to spill impact be conducted. Recognizing the high cost and time required to perform such studies, however, it is suggested that study locations be prioritized and selected only after sites having high spill probability have been identified. It is recommended that the Coast Guard initiate or influence the initiation of studies leading toward an understanding of food web dynamics, population and repopulation dynamics, and the economic value of different biological species. Finally, a concerted effort should be made to accurately characterize the effects of oil on flora and fauna of interest.

B. PHYSICAL DATA

Both the magnitude and direction of wind and current vectors must be accurately known at the time a spill occurs if one is to maximize his opportunities to invoke effective countermeasures. It may be argued that on-site observation can be employed at such times to effectively provide this information. Extreme weather and extended periods of darkness can prevent accurate observations, however. Moreover, lack of such information handicaps one's ability to plan-in-advance as, for example, investigating the need for special control measures for oil operations and transportation. This same lack of information handicapped the project team. Simplifying assumptions that were made regarding nearshore currents strongly influenced the degree of spill impact that was estimated for different spill cases. Information regarding the physical characteristics of rivers downstream of TAPS crossings was also found to be lacking by the project team. Finally, the need for a better understanding of nearshore ice dynamics and the degradation of oil in the Arctic environment was identified. It is recommended that studies be conducted to define nearshore currents at those locations where a high probability for oil spills has been determined.

A network of fixed stations to continuously signal wind direction and magnitude is in existance: consideration should be given to extending the system in locations of high spill probability.

It is further recommended that studies be initiated to define river characteristics below TAPS crossings. Also needed is information regarding the vertical dispersion of oil and its constituents in water columns. Near-shore ice dynamics need to be characterized at locations of interest as well. Finally, oil-specific studies should be undertaken which will define the relative biological toxicity and shore impact potential of oil with time in the Alaskan regime. It is also known that the rate of degredation can be affected by the degree of fertilization present; the effectiveness of such fertilization should be studied.

The study team developed a comprehensive model for analyzing the dispersion of oil on calm seas. No solid information was available with which to test the model's effectiveness against historical incidents, however. In this connection, it is recommended that the Coast Guard prepare a manual that defines time sequence observational data important to ground truthing such models and issue it to appropriate units for implementation of systamatic data gathering at future spills. This could supplement the existant Pollution Incident Reporting System (PIRS) now in use. Upon receipt of such data, analytical models should be modified as necessary. Of particular importance in this regard is more fundamental information regarding the spread of oil under sea ice. Also, specific information concerning observed water-in-oil emulsion formation and subsequent transport of such emulsion should be compiled.

C. SPILL CLEANUP

The study investigators identified combustion on site as a potentially effective method for disposing of oil in sea ice regimes. The dispersion of combustion products downwind of a disposal site and their effect on the albedo and the ecology required prior understanding and should be studied. Methods for disposing of recovered oil at other locations also require careful examination. Finally, the performance of pickup and containment equipment that has been tested in calm water and is currently undergoing rough sea testing requires testing in sea ice environments. Dispersants are currently used as the primary method of combating oil spills by most foreign countries. USCG strike team personnel observing and/or advising on such spill incidents as they occur around the world should systematically gather data bearing on toxicity of oil and/or dispersant as well as investigate synergistic effects in real spill incidents. Appropriate guidelines as to what type of information is needed and how to acquire it need to be developed.

An additional recommendation would be to require shippers to file cargo specification data which would be valuable in oil spill response operations by the U.S. Coast Guard. Minimal parameters required of cargoes are (1) specific gravity as a function of temperature, (2) viscosity as a function of temperature, (3) surface tension, and (4) pour temperature.

D. SPILL RESPONSE

A lesson continually brought home to the study investigators in the course of this study was the need for rapid spill response to minimize spill damage. This particularly applied to spills in confined waters. Natural dispersion mechanisms act so quickly at many locations that countermeasures, if any, need to be rapidly applied. It follows that prevention is the better part of the "cure." In this regard, tanker route selection and traffic control measures warrant careful definition; so also do the design and location of pipelines and shoreside transfer and storage locations.

In some situations, there will be sufficient time following a spill to effect useful countermeasures. In this regard, it is recommended that the selection of staging area sites be made with an eye toward logistic effectiveness and damage to the environment resulting from the staging areas themselves. It is also urged that consideration be given to predigitizing shoreline contours, currents, cleanup equipment inventories-response times, and biological data at "high risk" locations, together with a spill dispersion model, so that appropriate data can quickly be made available to response teams.

As previously noted, severe weather and extended darkness may handicap the tracking of slick boundaries. Such conditions may also inhibit the initial detection of spills. It is recommended that strong consideration be given to establishing fixed, remote monitoring stations at some locations. Techniques exist that can be adapted for this purpose. Techniques for detecting oil under ice is clearly another subject deserving of investigation.

APPENDIX A

DISTRIBUTION OF MARINE ALGAE IN ALASKA

APPENDIX A. DISTRIBUTION OF MARINE ALGAE IN ALASKA

Very little is known of the marine algae of Alaska, especially in view of the extensive rocky coasts which are suitable for the growth of these plants in Alaska. Kjellman[1] was one of the first to collect extensively in the Bering Sea and report on the algal communities. Kjellman[1] suggested the existence of an Aleutian flora with a "southern" boundary at Unalaska Island and a northern boundary at Bering Strait. In a later paper,[2] the southern boundary of the Arctic flora was stated to be at Bering Strait. The phytogeography of the Alaskan coast south and east of the Aleutian Islands was discussed by several authors.[3-9] The most recent paper[4] suggested that a transitional region occurs in the vicinity of Sitka in southeastern Alaska. Recent papers that have been published on the distribution of some of the kelps[10-13] indicated that most of the large species that form floating kelp beds do not occur north of the Alaska Peninsula. Studies in the Aleutian Islands[14-18] appear to confirm the presence of a number of species which are endemic to the area. In terms of phytogeography of seaweeds, it appears that the Alaskan coast can be divided roughly into three major areas (Table A-1). Because almost no collections of marine algae have been made between the Alaska Peninsula and Bering Strait, the transition between the Aleutian and Arctic floras is unknown. For the purposes of this report, the Arctic flora is arbitrarily assigned to those coasts with shore-fast ice in Winter, i.e., from the north side of the Alaska Peninsula northward.

REGIONAL TYPES OF MARINE ALGAE

In most studies of marine algal communities, the initial division is between the intertidal (littoral) and subtidal (sub-littoral) regions. The intertidal region is that area of the shore between the highest high tide level and the lowest low tide level. Because oil tends to float on the surface of the sea, and this floating portion would come into direct contact with the plants of the intertidal region, this division of communities is used in this report.

According to Scagel,[4] the intertidal flora is more cosmopolitan* because in one locality the plants tolerate much greater environmental extremes than those of the subtidal region; thus they can occur over a larger geographical area. Although there exist lists of intertidal species collected in Alaska,[1-3,15-28] none of these surveys covers, in any detail, the distribution and ecology of the species. The only studies dealing with these topics have been in the Aleutians[14] and in south Alaska.[29] According to Kjellman,[1,2] the intertidal flora of the Arctic coast of Alaska is very reduced or lacking. A comparison of the major intertidal zones of the Aleutian and south Alaskan areas is given in Table A-2. When differences in exposure and methods in the two studies are taken into account, together with the fact that the Prince William Sound study was made in an earthquake-disturbed area, there is general agreement in the major zones. Thus, although species composition may differ slightly, the community structure of the two areas is probably very similar.

---

*Cosmopolitan--found everywhere or over a relatively large area.

The subtidal region extends from the lowest low tide level downward. The lower limit of marine plants is not easily defined because it depends directly on the amount (and possibly the wavelengths) of light which reaches the bottom. This is affected by many variables such as aspect, water clarity, etc. Lack of rock substrate also limits plants in the subtidal. Generally, along a unit of shoreline, much more area is occupied by the subtidal flora than the intertidal flora. It is probably reasonable to assume that on the average the type of substrate in the subtidal region is the same as that of the adjoining shore. For lack of a better estimator of this parameter, this assumption has been used to estimate the theoretical subtidal vegetation as described elsewhere in this report. Even less is known of the subtidal vegetation in Alaska than is known of the intertidal vegetation. However, it is presumed that the differences between the subtidal floras of the Arctic, Aleutian and south Alaskan areas are greater than those of the intertidal region.[4] One indication of the community differences is the fact that floating kelps, which form extensive beds in the Aleutian and south Alaskan areas, are totally lacking from the Arctic area.[13] In the Aleutian area there is only one species of floating kelp, *Alaria fistulosa*,[13,14] whereas in the south Alaska area both *A. fistulosa* and *Nereocystis* form floating kelp beds.[13,30] Because of the direct influence of an oil spill on floating kelps and their importance in structuring algal communities, floating kelp beds are given a separate category even though they are technically a part of the subtidal vegetation. The type of algal vegetation expected at each site is indicated in Table A-3.

Native (subsistence) use of seaweeds for food and raw materials was undoubtedly frequent before the exploitation of Alaska by white men but is probably nonexistent now. No commercial harvesting of algae is known to occur in Alaska, although there would appear to be possibilities for future exploitation. Because plants form the ultimate source of food in all food webs, they are essential to the maintenance of an ecosystem and thus they have a great "ecological importance."

EELGRASS

An important member of the marine plant communities of Alaska is the flowering vascular plant *Zostera marina* (eelgrass). This plant occurs in the shallow subtidal region on non-rocky bottoms and has recently been studied extensively in Alaska.[31,32,33] Reports of this plant were also made by Johansen[29] in Prince William Sound. In some areas, eelgrass forms extensive meadows and forms major feeding grounds during short periods of the Spring and Fall for large numbers of migrating waterfowl (e.g., black brant in Izembek Lagoon near Port Moller). Consequently, these eelgrass beds are critical in supporting large waterfowl populations and have a high "ecological importance." No subsistence or commercial use of this plant occurs in Alaska.

TABLE A-1. MAJOR PHYTOGEOGRAPHICAL AREAS OF MARINE ALGAE IN ALASKA AND THEIR ASSUMED OR INFERRED BOUNDARIES

NAME (1)	BOUNDARIES (2)
South Alaskan	Sitka to Alaska Peninsula
Aleutian	Aleutian Islands
Arctic	Alaska Peninsula northward

TABLE A-2. COMPARISON OF MAJOR INTERTIDAL ALGAL ZONES IN ALASKA

RELATIVE LEVEL (1)	SOUTH ALASKAN[1] (2)	ALEUTIAN[2] (3)	ARCTIC[3] (4)
Highest	*Prasiola*	*Prasiola*	(very sparse or lacking)
	Verrucaria		
	Blidingia	*Rhodochorton*	
	Gloiopeltis		
	Fucus	*Fucus-Porphyra*	
	Rhodymenia	*Hedophyllum-Halosaccion*	
	Alaria	*Alaria*	
Lowest	*Laminaria*	*Laminaria*	

[1] (29)

[2] (14)

[3] (1)

TABLE A-3. SPILL SITES ACCORDING TO MAJOR ALGAL VEGETATION AREAS

ALEUTIAN (1)	SOUTH ALASKAN (2)	ARCTIC (3)
Unimak Pass	Yakutat	Port Moller
	Valdez Harbor	Kvichak Bay
	Valdez Narrows	St. Matthew Island
	Offshore Port Graham	Nome
	Kamishak Bay	Cape Blossom
	Drift River	Offshore Prudhoe
		Onshore Prudhoe

APPENDIX A. REFERENCES

1. Kjellman, F. R., "Om Beringhafvets Algflora," *K. SVENSKA VET.-AKAD. HANDL.*, 23(8):58 pp. 7, 1889.

2. Kjellman, F. R., "The Algae Of The Arctic Sea," *K. SVENSKA VETENSK.-AKAD. HANDL.*, 20(5): 1-350 pp. +1, 31 pls., 1883.

3. Setchell, W. A. and N. L. Gardner, "Algae Of Northwestern America," *U. CAL. PUB. BOT.*, 1:165-418, pls. 17-27, 1903.

4. Scagel, R. F., *DISTRIBUTION OF ATTACHED MARINE ALGAE IN RELATION TO OCEANOGRAPHIC CONDITIONS IN THE NORTHEAST PACIFIC,"* in: M. J. Dunbar (ed.) Marine Distributions, Univ. Toronto Press, Roy. Soc. Canada Spec. Publ. No. 5:37-50, 1963.

5. Setchell, W. A., "On The Classification And Geographical Distribution Of The Laminariaceae," *TRANSO CONNO ACAD.*, 9:333-375, 1893.

6. Setchell, W. A., "Geographic Elements Of The Marine Flora Of The North Pacific Ocean," *AMER. NAT.*, 69:560-577, 1935

7. Scagel, R. F., *COASTAL STUDIES OF MARINE ALGAE IN BRITISH COLUMBIA AND THE NORTH PACIFIC,* Coastal and Shallow Water Research Conf., pp. 748-750.

8. Scagel, Robert F., "Marine Algal Distributions Across In The North Pacific," *PROC. 11TH PAC. SCI. CONG.*, 7:9, 1966.

9. Scagel, R. F., *SOME PROBLEMS IN ALGAL DISTRIBUTION IN THE NORTH PACIFIC,"* Proc. 4th Int. Seaweed Sym., pp. 259-264, 1963.

10. Druehl, Louis, "Taxonomy And Distribution Of Northeast Pacific Species Of *Laminaria*," *CAN. J. BOT.*, 46:539-548, 1968.

11. Widdowson, T. B., "A Taxonomic Revision Of The Genus Alaria Greville," *SYESIS*, 4(1 & 2):11-50, 1971.

12. Widdowson, Thomas B., "A Taxonomic Study Of The Genus Hedophyllum Setchell," *CANADIAN J. BOTANY*, 43:1409-1420, 1965.

13. Druehl, L. D., "The Pattern Of Laminariales Distribution In The Northeast Pacific," *PHYCOLOGIA*, 9(3/4):237-247, 1970.

14. Lebednik, P. A., F. C. Weinmann, and R. E. Norris, "Spatial And Seasonal Distributions of Marine Algal Communities At Amchitka Island, Alaska," *BIOSCIENCE*, 21(12):656-660, 1971.

APPENDIX 2. REFERENCES (CONT'D.)

15. Wynne, M. J., "Marine Algae Of Amchitka Island (Aleutian Islands), I. Delezzeriaccae," *SYESIS*, 3:95-144, 1970.

16. Wynne, M. J., "Marine Algae Of Amchitka Island (Aleutian Islands), II. Bonnemaisoniaccae," *PACIFIC SCIENCE*, 24(4):433-438, 1970.

17. Wynne, M. J., *THE GENUS PORPHYRA AT AMCHITKA ISLAND, ALEUTIANS,"* Proc. Fth. Int'l. Seaweed Symposium, pages 100-104, 1971.

18. Wynne, M. J., *OBSERVATIONS ON A NEW GENUS OF BONNEMAISONIACCAE (RED ALGAE) FROM AMCHITKA ISLANDS, ALEUTIANS*, Abs. 11th Int'l. Bot. Cong., page 244, 1969.

19. Chihara, Mitsuo, "Some Marine Algae Collected At Cape Thompson Of The Alaska Arctice," *BULL. NAT. SCI. MUS.*, 10(2):183-200, pl. 1-4, 1967.

20. Dawson, E. Y., "A Guide To The Literature And Distributions Of Pacific Benthic Algae From Alaska To The Galapagos Islands," *PAC. SC.*, 15: 370-461, 1961.

21. Dawson, E. Y., "A Guide To The Literature And Distributions Of The Marine Algae Of The Pacific Coast Of North America," *MOM. S. CAL. ACAD. SCI.*, 3:1-134, 1946.

22. Mohr, J. L., N. J. Wilmovsky, and E. Y. Dawson, "An Arctic Alaskan Kelp Bed," *ARCTIC*, 10:45-52, 2 figs., 1957.

23. Okamura, K., "On The Algae From Alaska Collected By Y. Kobayashi," *REC. OCEAN. WORKS IN JAPAN*, 5(1):85-97, pl. 4, 5, 1933.

24. Saunders, deA., "Papers From The Harriman Alaska Expedition, XXV. The Algae Of The Expedition," *PROC. WASH. ACAD. SCI.*, 3:391-486, pages 43-62, 1901.

25. Setchell, W. A., *XXIV. ALGAE OF THE PRIBILOF ISLAND, PP. 589-596 + PL.XCV*, in: "The Fur Seals And Fur-Seal Islands Of The North Pacific Ocean by D. S. Jordan, Part III Special Papers Relating To The Fur Seal And To The Natural History Of The Pribilof Island, Govt. Printing Office, Wash. D.C., 1899.

26. Scagel, R. F., "An Annotated List Of The Marine Algae Of British Columbia And Northern Washington," *NAT. MUS. CANADA. BULL.*, 150, 289 pages + map, 1957.

APPENDIX 2. REFERENCES (CONT'D.)

27. Scagel, R. F., "Marine Algae Of British Columbia And Northern Washington, Part I: Chlorophyseac (Green Algae)," *NAT. MUS. CANADA. BULL., 207*, 247 pages, 49 plates, 1966.

28. Collins, F. S., *MARINE ALGAE FROM BERING STRAIT AND ARCTIC OCEAN COLLECTED BY THE CANADIAN ARACTIC EXPEDITION, 1913-1916*, in: Report Canadian Aractic Exp. 1913-1918, vol. IV (part B) - pp. 3-16, plate I, 1927.

29. Johansen, H. W., *EFFECTS OF ELERATION CHANGES ON BENTHIC ALGAE IN PRINCE WILLIAM SOUND*, in: "The Great Alaska Earthquake Of 1964," Nat. Acad. Sci., Wash., D.C. - Publ. 1964 - pp. 35-68, 1971.

30. Rigg, G. B., "The Kelp Beds Of Western Alaska," *POTASH FROM KELP INVESTIGATION, U.S.D.A. RPT. 100*, pages 105-122, maps A-B, 1915.

31. McRoy, C. Peter, "The Distribution And Biogeography Of *Zostera marina* (eelgrass) In Alaska," *Pac. Sci.*, 22(4):507-513, 1968.

32. McRoy, C. P., "Eelgrass Under Arctic Winter Ice," *NATURE*, 224(5221): 818-819, 1969.

33. McRoy, Peter, "A Eurasian Alga In Alaska," *PACIFIC SCIENCE*, 22(1): 138, 1968.

APPENDIX B

SUMMARY OF TOXIC RESPONSE FOR MARINE FLORA AND FAUNA

SUMMARY OF TOXIC RESPONSES FOR MARINE FLORA

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Phyto-Plankton	*Dinobryon* Sp. *Peridinum* Sp.	FIELD (freshwater pond, June-October)	M.S.O. crude 4.5 1/6 diam. test area (film on surface)		117 days (whole experiment)	growth suppressed	1	
Phyto-Plankton	*Tabellaia* Sp. *Ankistrodesmus spirales*	FIELD (freshwater pond, June-October)	M.S.O. crude 4.5 1/6 diam. test area (Film on surface)		117 days (whole experiment)	growth stimulated	1	
Phyto-Plankton	*Fragillaria* Sp. *Ankistrodesmus falcatus*	FIELD (freshwater pond, June-October)	M.S.O. crude 4.5 1/6 diam. test area (film on surface)		117 days (whole experiment)	no response	1	volatilization and bacterial degradation
Phyto-Plankton	*Chlorococcum* Sp.	LABORATORY	Soluble extract from 50 ml in 1 ℓ water 0, 25, 50, 75, 100% "saturation"	1-5 ppm 100% "saturation"	10 days	no response	1	
Phyto-Plankton	*Cosmarium* Sp.	LABORATORY	Soluble extract from 50 ml in 1 ℓ water 0, 25, 50, 75, 100% "saturation"	1-5 ppm 100% "saturation"	12 days	growth inversely proportional to % saturation	1	
Phyto-Plankton	*Chlorella vulgaris*	LABORATORY	Soluble extract from 50 mk "Gulf" crude in one ℓ water 0, 10, 25, 50, 75, 90% "Saturation"	1-5 ppm 100% "saturation"	10 days	growth suppressed	1	suppression attributed to a decrease casued by oil
Phyto-Plankton	*Chlorella vulgaris*	LABORATORY	Benzene	25-500 ppm	10 days	initial inhibition for 2 days, then growth	1	4 day LD_{50} = 650 ppm (our estimate from Kauss data)
				500-1744 ppm	10 days	lethal toxicity		

B-1

SUMMARY OF TOXIC RESPONSES FOR MARINE FLORA

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Phyto-Plankton	*Chlorella vulgaris*	LABORATORY	Tuluene	25-250 ppm 500 ppm	10 days 10 days	slight inhib. lethal toxicity	1	4 day LD_{50} = 175 ppm (our estimate from Kauss data)
Phyto-Plankton	*Chlorella vulgaris*	LABORATORY	O-Xylene	25-50 ppm	10 days	slight inhib. lethal toxicity	1	4 day LD_{50} = 70 ppm
Phyto-Plankton	*Chlorella vulgaris*	LABORATORY	7 Alberta crudes concentrations unknown	25-50 ppm	10 days	2 day inhibition then stimulation	1	
Phyto-Plankton	*Chlorella vulgaris*	LABORATORY	Smiley Colville (an Alberta crude) soluble extract		10 days	slight inhibition over 10 day period	1	
Phyto-Plankton	Numerous Species	LABORATORY	"oil" .00001-1.0 ml/ℓ; most used .001-1. ml/ℓ	(0.01-1000. ppm)	5 days	death 1 ml/ℓ·)1000 ppm delayed cel division 1.0-0.001 ml/ℓ no effect .01-0.001 ml/ℓ (10-0.01 ppm)	1	does not describe oil used or whether concentrations quoted are soluble or not
Inter-tidal plants surf grass	*Phyllospadix torreyli*	Incident - Santa Barbara	Weathered crude heavy coating		one tidal cycle	death thru coating and abrasion (smothering)	1	

SUMMARY OF TOXIC RESPONSES FOR MARINE FLORA

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDROCARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Green algae (mid & high intertidal)	*Enteromorpha intestinalis*	Incident - Santa Barbara	Heavy coating various coatings			slight damage except where completely coated	1	most intertidal algae have a mucous coat which sheds oil; high intertidal plants, where oil dried were damaged, season important - i.e. blooms, subtidal plants not affected
	Chaetomorpha aerea	Incident - Santa Barbara	Heavy coating various coatings					
	Ulva californica	Incident - Santa Barbara	Heavy coating various coatings			U. californica recovered in 4 months		
Brown algae	*Egregia laevigata*	Incident - Santa Barbara	various coatings			little damage		
Red Algae	*Porphyra* Sp.	Incident - Santa Barbara	various coatings			killed-holds oil		
Kelp	*Macrocystis angustifolia*	Incident - Santa Barbara	heavy coating			no damage - mucous coat	1	
Kelp	*Macrocystis angustifolia*	Tampico Maru LABORATORY	diesel fuel 0.01%-1% emulsion	1-100 ppm	7 days	loss of photosynthability	1	Tampico Maru spill resulted in kills to members all phyla.
Salt marsh grasses	*Spartina townsendii*	Incidents: Milford Haven & Torrey Canyon	fresh crude		20 min. (M.H.) after spill	75-100% killed	1	many other marsh plants studied but not summarized here
	Puccinellia maritima	weathered crude (& dispersants)			8 days (T.C.)			

SUMMARY OF TOXIC RESPONSES FOR MARINE FLORA

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Macrophytic algae		Incident: Torrey Canyon	weathered crude and dispersants			algae increased coverage of rocks	1	oil & dispersants killed herbivores, so algae overgrew rocks
Phyto-Plankton	*Prasinophyceae* *Haloephaera* Sp. *Pteroeperma* Sp.	Incident: Torrey Canyon	crude slick			lethal toxicity (reduced population)	1	Cysts (reprod cells) of these were disrupted by oil, since they float near surface
Phyto-Plankton	Various Species	LABORATORY	BP 1002 emulsifier without kerosene	1.2×10^{-3} ppm 1.2 ppm		generation time & lag phase lengthened below 1.2 ppm lethal toxicity at 1.2 ppm	1	brackish water species better able to withstand membrane damage caused by emulsifier (sol'n in lipid layer)
Salt marsh grasses	Various Species	FIELD - experiment (Milford Haven)	fresh crudes (Kuwait)			see p.31 of Cowell annuals most susceptible; perennials most resistant	1	germination in annuals inhibited seasonally dependent
Kelp	*Macrocystis angustifolia*	LABORATORY	benzene n-hexane toluene	10 ppm 10 ppm 10 ppm	96 hrs. 96 hrs. 96 hrs.	slight photosynth. inhib. no effect visible injury, 75% reduction in photosyn.	1	

SUMMARY OF TOXIC RESPONSES FOR MARINE FLORA

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Algae (sea wrack)	*Fucus serratus*	FIELD - (spill) observations	Bunker C			on impli-cated is breaking loose *Fucus*	2	Arrow in.ident
Alqae (sea wrack)	*Fucus spiralis*	FIELD - (spill) observations	Bunker C			reduced or eliminated within 10 mos. - little reco-lonization	2	Arrow incident

SUMMARY OF TOXIC RESPONSES OF FINFISH

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Atlantic Salmon	*Salmo salar*	LABORATORY	Corexit 8666 1-10,000 mg/ℓ complete emulsion		7-14 days	4 day LD_{50} >10,000 mg/ℓ	1	authors point out probability of sub-lethal-long-term effects of oil dispersant at lower conc.
Atlantic Salmon	*Salmo salar*	LABORATORY	1-10,000 mg/ℓ complete emulsion BP 1100 B BP 1100 Gulf agent 1009 Naphtha gas Dispersant 88 Dispersol SD BP1002 XZIT x-1-11	2-2000 ppm	7-14 days	4 day LD_{50} 1-100 mg/ℓ		authors believe Corexit is microbially degraded; the byproducts of this process, either from Corexit or waste from microbes are toxic after 7 day's building in test tank.
Atlantic Salmon	*Salmo salar*	LABORATORY	1-10,000 mg/ℓ temporary emulsion Bunker C	0-1 ppm	7-14 days	4 day LD_{50} >10,000 mg/ℓ 7 day LD_{50} ∿ 2000 mg/ℓ		
Atlantic Salmon	*Salmo salar*	LABORATORY	Bunker C & Corexit 8666		7-14 days	4 day} 7 day} LD_{50} ≡100-1000 mg/ℓ		
Flounder (winter)	*Pseudopleuronectes americanus*	LABORATORY	Bunker C & Corexit 8666		7-14 days	4 day LD_{50} >10,000 mg/ℓ 7 day LD_{50} ∿1000 mg/ℓ		

SUMMARY OF TOXIC RESPONSES OF FINFISH

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Fresh water fish	*Mugil saliens* *Sargus annularis* *Crenilabrus tenca*	LABORATORY	"oil" 0.25 ml/ℓ		"many days" "several days"	no effect	1	emulsion more toxic than film
Plaice	*Rhombus maeoticus*	LABORATORY	"oil" 10^{-4}-10^{-5} ml/ℓ		2 days	lethal toxicity to eggs	1	
Shad	*Alosa sapidissima*	LABORATORY	Gasoline #2 Diesel fuel Bunker C	0.204 ml/ℓ 0.167 ml/ℓ	24 hrs. 48 hrs.	LD_{50} 24 48 96 Gas 91 91 - #2 204 167 - C - 2,417, 1,952	1	loss of toxicity by evaporation
Mullet	*Mugil cephalus* *Micropogon undulatus*	LABORATORY	#2 Diesel oil 0.01-10% emulsified	0.002-2 ppm	LD_{50} (48 hrs.) 420 ppm (acute) LD_{50} (chronic) 42 ppm	LD_{50} (48 hr.) 420 ppm (acute) LD_{50} (chronic) 42 ppm	1	safe at 4.2 ppm
Poach	*Rutilus* Sp.	LABORATORY	cyclohexane benzene methylcyclohexene	10 ppm 10 ppm 10 ppm	3-4 hrs.	lethal toxicity	1	
Sunfish		LABORATORY	Phenanthrene Naphthalene Xylene, toluene benzene, ethylene	4-5 ppm 4-5 ppm 22-65 ppm	1 hr.	lethal toxicity	1	
Thread herring	*Ophistonema orglinum*	Incident: Ocean Eagle San Juan	crude oil & emulsifiers			95% of schools near spill had lesions	1	
Mummichog	*Fundulus heteroclitus*	LAB. BIOASSAY	crude oil	16.5 ml/ℓ		48 hrs. LC 50	3	

SUMMARY OF TOXIC RESPONSES OF FINFISH

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Mummichog	*Fundulus heteroclitus*	LAB. BIOASSAY	oil dispersant	0.01 ml/ℓ		48 hrs. LC 50	3	
Mummichog	*Fundulus heteroclitus*	LAB. BIOASSAY	10 parts crude/1 part (u/u) emulsifier	0.251 ml/ℓ			3	
Toadfish	*Opsanus tau*	LABORATORY	Diesel oil			toxic	4	
Cotlo Salmon & sockeye salmon	*Oncorhynchus kisutch & O. nerka*	STATIC BIOASSAYS	Prudhoe Bay crude	500-3500 ppm	96 hrs.	10-100% mortalities	5	loss of equilibrium & other stress behavior @ 500 ppm & higher
Tadpole soulpin	*Psychrolutes paradoxus*	STATIC BIOASSAY	#2 Diesel	0.398 ml/ℓ		48 hrs. LC 50	6	salinity 30‰
Chinook Salmon	*Oncorhyuchus tshawytscha*	STATIC BIOASSAY	#2 Diesel	1.19 ml/ℓ		48 hrs. LC 50	5	Freshwater
Pink Salmon	*Oncorhynchus gorbuscha*	STATIC BIOASSAY	#2 Diesel	0.550 ml/ℓ		48 hrs. LC 50	6	salinity 30‰
Chum Salmon	*Oncorhynchus keta*	STATIC BIOASSAY	#2 Diesel	0.538 ml/ℓ		48 hrs. LC 50	6	salinity 25‰
Zadiated Shanny	*Ulvaria subbifurcata*	FIELD (spill) observations	Bunker C			washed ashore 22 days after initial spill	7	Arrow incident
Shorthorn Sculpin	*Myoxocephalus scorpius*	FIELD (spill) observations	Bunker C			washed ashore 22 days after initial spill	7	Arrow incident

SUMMARY OF TOXIC RESPONSES OF FINFISH

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Seasnail	*Liparis atlanticus*	FIELD (spill) observations	Bunker C			washed ashore 22 days after initial spill	7	Arrow incident
Rock Gunnel	*Pholis gunnellus*	FIELD (spill) observations	Bunker C			washed ashore 22 days after initial spill	7	Arrow incident
Bluegill Sunfish	*Lepomis macrochirus*	BIOASSAY	#4 fuel oil (in freshwater)	44 mg/ℓ (6 fish/6ℓ) 91 mg/ℓ (10 fish/18ℓ)		24 hrs. LC 50	8	
Bluegill Sunfish	*Lepomis macrochirus*	BIOASSAY	#4 fuel oil w/1 mg/ℓ linear alkyate sulfonate	<10 mg/(6 fish/6ℓ) 51 mg/ℓ(10 fish/18ℓ)		24 hrs. LC 50	8	
Bluegill Sunfish	*Lepomis macrochirus*	BIOASSAY	Linear alkylate sulfonate	2.2 mg/ℓ		24 hrs. LC 50	8	Do = 7.5 mg/ℓ 24° C
Bluegill Sunfish	*Lepomis macrochirus*	BIOASSAY	Methyl ester of 2 methyl propenoic acid	>43 mg/ℓ		48 hrs. LC 50	9	
Bluegill Sunfish	*Lepomis macrochirus*	BIOASSAY	O-Phthalate	>43 mg/ℓ		48 hrs. LC 50	9	
Rainbow Trout	*Salmo gairdneri*	LABORATORY	Diesel oil			toxic	10	

SUMMARY OF TOXIC RESPONSES OF GASTROPODS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDROCARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Dog Whelk Peri-winkle	*Nucella lapidus* *Littorina littorea*	INCIDENT	"dispersants"			more resistance than crustaceans	1	Gastropods can produce copious mucus secretion
Peri-winkle	*Littorina littorea*	INCIDENT: ARROW	Bunker C			ingestion of oil - no effect	1	intertidal contact with oil - oil passed through digestive system unmodified - no uptake in other organs
Peri-winkle	*Littorina littorea*		fresh crude oil			"sensitive"	1	
Limpets	*Acmea* Sp.	INCIDENT: Santa Barbara	weathered crude oil	heavy coat		little damage	1	limpets appeared to be feeding on oil
Peri-winkle Peri-winkle Limpet Dog Whelk	*Littorina neritoides* *Littorina saxatilis* *Patella vulgata* *Thais lapillus* *Gibbula umbilicalis* *Littorina obtusata*	FIELD	Kuwait crude (fresh) Kuwait crude (weathered) DP 1002 (single) in combination) $\sim 2\ \ell/m^2$		5 min.-6 hrs.	general relative toxicity to gastropods BP 1002 > fresh >> weathered	1	data difficult to summarize by species experiments were small scale & contained many uncontrolled variables, making quantification of results difficult

SUMMARY OF TOXIC RESPONSES OF GASTROPODS

ORGANISM COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Same 6 Species as Above		LABORATORY	BP 1002 BP 1100			toxicity dependent on season; least toxic in winter (water temp. 10° C) highest in summer (water temp. 18°C) BP 1002 much more toxic than BP 1100	1	same comments as above
Limpet Periwinkle Periwinkle		LABORATORY	various crudes		sprayed on for 1 hr. then washed	1-89% mortality for L. littoralis. L. littorea very resistant. P. vulgata very sensitive	1	high mortality correlates with asphaltenes & low boiling compounds (aromatics, especially).
Periwinkle Dog Whelk Top-Shell Limpet		LABORATORY	BP 1002 0-100 ppm	0-20 ppm	24 hrs. 24 hrs.	$LD_{50} \sim 100$ ppm $LD_{50} \sim 100$ ppm $LD_{50} = 100$ ppm $LD_{50} = 5$ ppm	1	intertidal species periwinkles may recover from 100 ppm all detach from substrate before dying

SUMMARY OF TOXIC RESPONSES OF GASTROPODS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Limpet	*Patella vulgata*	LABORATORY	BP 1002			96h LD_{50} = 5 ppm	1	data supports Ottway's conclusions
Peri-winkle	*Littorina littoralis*	LABORATORY	0-200 ppm BP 1002	0-400 ppm		24h LD_{50} = 250 ppm		
Peri-winkle	*L. littorea*	LABORATORY	0-200 ppm BP 1002			24h LD_{50} = 2000 ppm		
Peri-winkle	*L. littorea*	LABORATORY	crude oil weathering BP 1002			weathered oil less toxic than oil & BP 1002	1	oil weathered for 24h in lab. simulated tidal washing in lab.
Limpets	*Acmaea* Sp.	STATIC BIOASSAY	#2 Diesel	0.0229 ml/ℓ		48 hrs. median effective concentration (narcotization)	11	narcotization recovery after 48 hrs. in running seawater 50-100%
Wrinkled Purple Snails	*Thais lamellosa*	STATIC BIOASSAY	#2 Diesel	0.059 ml/ℓ		48 hrs. median effective concentration (narcotization)	11	Narcotization recovery after 48 hrs. in running seawater 50-100%
Peri-winkle	*Littorina littorea*	DIRECT COATING	Arabian light crude		2-12 hrs.	50% mortality	12	cited from Legore (1974)

SUMMARY OF TOXIC RESPONSES OF GASTROPODS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDROCARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Limpets	*Patella vulgata*	BIOASSAY	fresh Kuwait oil			Midnight >44-58% detached from substrate Fam. >9.5-19% detached from substrate	13	
Mud Snail	*Nassarius obsoletus*	BIOASSAY - SUBLETHAL	water sol. extract of kerosene			interference with attraction to food extracts	14	cited from Atema & Stein (1974)
Periwinkle	*Littorina saxatilis* *L. littorea* *L. obtusata*	FIELD (spill) observations	Bunker C			no detectable effect	15	Arrow incident
Periwinkle	*Littorina littorea*	STATIC BIOASSAY	Bunker C	750-800 μg/ℓ		crawling & respiration rates increased	16	20°C greater change than @ 4° C
Periwinkle	*Littorina littorea*	STATIC BIOASSAY	Corexit 8666 (surface active dispersant)	10 ml/ℓ		crawling & respiration rates decreased	16	20°C greater change than @ 4°C
Periwinkle	*Littorina littorea*	STATIC BIOASSAY	Bunker C	(combined)		crawling & respiration rates increased	16	20°C greater change than @ 4°C

SUMMARY OF TOXIC EFFECTS OF OIL ON MARINE BIVALVES (SHELLFISH)

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Oysters		LABORATORY	BP1002	~2-20 ppm		10-100 ppm BP1002 lethal	1	
Cockles	*Cardium edule*		phenol			48LD$_{50}$ = 500 ppm	1	
Mussel	*Mytilus edulis*	LABORATORY	"laboratory" weathered (24 hrs.) Arabian crude plus Corexit or Dispersol approximately 0.5 ml/cm^2 + 10% dispersant		4 tidal cycles	no toxicity for crude oil only; 50% mortality with Dispersol plus oil	1	simulated tidal conditions
Mussels	*Mytilus californianus*	LABORATORY	0-10^5 ppm Sarta Barbara crude (as surface film)	0-100 ppm	34 days	10^4 and 10^5 ppm caused significant mortality	1	individual from area (Coal Point) subject to natural seeps possibly less susceptible than those from other areas; data not conclusive
Mussels	*Mytilus edulis*	LABORATORY	1000 mg/ℓ mineral oil (paraffin only)	0	up to 6 days	no mortality	1	primarily an experiment to investigate uptake and incorporation
			1-8 mg/ℓ heptadezane	0	up to 6 days	no mortality		
			100 ppm tetralin	100 ppm	up to 6 days	toxic		
			1 ppm toluene, napthalene, 3,4-benzpyrene	1 ppm	up to 6 days	not toxic		

SUMMARY OF TOXIC EFFECTS OF OIL ON MARINE BIVALVES (SHELLFISH)

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Cockles	*Cardium edule*	LABORATORY	detergents	0-20 ppm	variable	$48LD_{50}$ for BP1002 81 ppm	1	$48LD_{50}$ for many detergents given
Mussel	*Modiolus modiolus*	FIELD (Arrow Spill)	Bunker C			oil content 100-125 μg/gm	1	incorporation of Bunker C after Arrow Spill
Mussel	*Mytilus edulis*	LABORATORY	BP1002	~ 4 ppm		$24LD_{50}$ = 90 ppm $48LD_{50}$ = 2 ppm	1	
Cockle	*Cardium edule*	LABORATORY	BP1002	~4 ppm		$24LD_{50}$ = 20 ppm	1	
Mussel	*Mytilus edulis*	LABORATORY	0-100 ppm BP1002	0-20 ppm	24 hrs.	5 ppm BP 1002 not lethal in 24 hrs; 10 ppm BP 1002 lethal	1	also obtained information on sub-lethal concentrations
			1000 ppm crude emulsion	~60 ppm	24 hrs.	no deaths, but mussels could not attach properly		
Razor Clam	*Ensis siligua*	LABORATORY	BP 1002			24 hrs. LD_{50} = 0.5 ppm	1	subtidal species
Queen Scallop	*Chlamys opercularis*					24 hrs. LD_{50} = 1 ppm		

SUMMARY OF TOXIC EFFECTS OF OIL ON MARINE BIVALVES (SHELLFISH)

ORGANISM: COMMON NAME (1)	ORGANISM: SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDROCARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Bay Mussel	*Mytilus edulis*	STATIC BIOASSAY	#2 Diesel	0.0156 ml/ℓ		48 hrs. median effective concentration (nargtiztion)	17	Narcotization recovery after 48 hrs. in running seawater
Oysters	*Ostrea edulis*	LABORATORY	Diesel			toxic	18	initial sublethal response retarded pumping rate
Bay Mussel	*Mytilus edulis*	DIRECT COATING	Arabian light crude			no mortality	19	cited from Legore (1974)
Oysters	*Crassostrea virginica*	FIELD EVALUATIONS	"volatile hydrocarbons"	0.177-1.680 ml/ℓ		no noticable effect	20	cited from Legore (1974)
Oysters	*Crassostrea virginica*	LABORATORY	water - gas tar			(1) no effect in continuous flow (2) "serious or fatal effects" in stagnant seawater	21	Resulted in lack of sensitivity to tactile stimulus deo. in mantle
Oysters	*Crassostrea angulata* & *Ostrea edulis*	LABORATORY - continuous flow	fuel oil	0.01 - 0.05% 0.1 - 0.5% 2.0%	1 mo.	no mortalities 9-10/12 died All died within 1 wk	22	
Softshell Clam	*Mya arenaria*	FIELD (Spill) observations	Bunker C			up to 73% mortality highly correlated with oil cover	23	

SUMMARY OF TOXIC EFFECTS OF OIL ON MARINE BIVALVES (SHELLFISH)

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Bay Mussels	*Mytilus edulis*	(spill) collected, polluted organisms	#2 fuel oil (Anacortes spill)	50 ppm Total paraffin hydrocarbons	2 mo. after spill		24	controls = 4.1 ppm
California Mussel	*Mytilus Californianus*	(spill) collected, polluted organisms	Navy special fuel oil	9,300 ppm Total paraffin hydrocarbons			24	controls = 4.0 ppm

SUMMARY OF TOXIC RESPONSES TO OILS OF PELAGIC CRUSTACEANS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Copepod	Several species	LABORATORY	0.001-0.1 ml/ℓ "oil"	(possibly 1-100 ppm)		insensitive to 0.001 ml/ℓ, 100% death with 0.1 ml/ℓ	1	experimental methods not described
Shrimp	*Penaeus* Sp. *Palaemonetes* Sp.	LABORATORY	crude oil plus emulsifiers (1-100 ¶)	(1-100 ppm)		$48LD_{50}$=1-40 ppm crude oil $48LD_{50}$=0.5-5 ¶ crude plus Corexit	1	see reference for detailed break-down; oils with higher proportion of aromatics most toxic
Copepod	*Calanus finmarchicus*	LABORATORY	1-50 ppm BP 1002 Gamlen Dasic Molyslip Houghton Solvent 112	0.2-10 ppm	1 hr.-3 days	50 ppm detergent caused 100% mortality in an hr.; 5-10 ppm detergents caused high mortality in 3 days; 1 ppm was injurious	1	
Copepod	*Acartia clausi*	LABORATORY	5-100 ppm BP 1002 Dasic	1-20 ppm	10-1000 minutes	lethally toxic at all concentrations	1	BP 1002 5 times as toxic as Dasic; Acartis much less resistant than Calamus; suggests sm. animals toxicity is related to size

SUMMARY OF TOXIC RESPONSES TO OILS OF PELAGIC CRUSTACEANS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Pink Shrimp	*Pandalus montagui*	LABORATORY	BP1002		48 hr. LD_{50}= 5.8 ppm	Portmann & Connor (1968)	1	
Zooplankton	(Copepods) *Temora longicornis* (dominant) (Calanus) *finmarchicus*	FIELD COLLECTIONS	Bunker C			10% oil in water column assoc. w/ Zooplankton Feces contained 7% No apparent effect on organisms 20% sedimented to bottom w/ Feces	25	Arrow incident

SUMMARY OF TOXIC EFFECTS OF OIL ON OTHER BENTHIC INVERTEBRATES

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Polychaete annelid	*Arenicola marina*	LABORATORY	BP 1002	6 ppm		96 hr. LD_{50} = 30 ppm	1	
Polychaete annelid	*Nereis diversicolor*	LABORATORY	BP 1002	5 ppm		24 hr. LD_{50} = 25 ppm	1	
Starfish	*Asterias rubens*	LABORATORY	BP 1002	6-8 ppm		24 hr. LD_{50} = 40 ppm 96 hr. LD_{50} = 30 ppm	1	
Anemones	2 Species	LABORATORY	BP 1002	5-10 ppm		24 hr. LD_{50} = 25-50 ppm	1	
Starfish	*A. rubens*	LABORATORY	BP 1002	5 ppm		24 hr. LD_{50} = 25 ppm	1	
Brittle-star	*Ophiocomina nigra*	LABORATORY		1 ppm		24 hr. LD_{50} = 5 ppm	1	
Coelent-erate	*Tubularia crocea*	LABORATORY	crude 0.1-5%			"quickly lethal"	1	
Coelent-erate	*Calliactis parasitica*	LABORATORY	BP 1002	5 ppm		24 hr. LD_{50} = 25	1	
Sandworm	*Nereis virens*	LABORATORY	"BP"			96 hr. LD_{50} = 165 ppm	1	only code names of 10 dispersants are given. Sandworm is one of most valuable marine products in New England

SUMMARY OF TOXIC EFFECTS OF OIL ON OTHER BENTHIC INVERTEBRATES

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Sandworm	*Nereis virens*	LABORATORY	"crude oil B"	0		96 hr. LD_{50} = 6100 ppm	1	
Polychaete annelid	*Cirriformia tentaculata*	INCIDENT: Shore terminal spill	fresh fuel oil coating on mud surface			little damage	1	Mucus secretions of worms and inability of oil to penetrate mud may have prevented toxicity
Polychaete annelids	*Cirriformia tentaculata*	INCIDENT: Shore terminal spill	fuel oil & Essolvene			high mortality	1	oil may have been dispersed into mud by emulsifier and ingested by worms
Polychaete annelids	*Cirriformia tentaculata*	LABORATORY	BP 1002 Essolvene Corexit 7664			24 hr. LD_{50} (ppm) C. Tentaculata BP 30 Essolvene 63 Corexit 100,000 C. cirratus BP 129 Essolvene 162 Corexit 100,000	1	

SUMMARY OF TOXIC EFFECTS OF OIL ON OTHER BENTHIC INVERTEBRATES

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Coral	*several species*	LABORATORY	Corexit (0-500 ppm) crude oil 0-500 ppm (slick) & mixtures		24 hrs.	harmful at 100-500 ppm (not necessarily completely in solution) dispersant more toxic than oil	1	crude oil concentrations given were not completely dissolved
Hydrozoans	*Tubularia crocea*	LABORATORY	Diesel oil			toxic	26	
Poly-chaetes	*Cirriformia tentaculata* *Cirratulus cirratus*	LABORATORY				heavy fractions not highly toxic to organisms	27	cited in Thomas (1973) - not seen -

SUMMARY OF TOXIC EFFECTS OF OIL ON MARINE BENTHIC CRUSTACEANS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Shrimp	*Crangon crangon*	LABORATORY	various emulsifiers	~1 ppm	48 hrs.	$48LD_{50}$ for BP1002 = 5.8 ppm	1	
Shore crab	*Carcinus maenas*	LABORATORY	various emulsifiers	~3 ppm	48 hrs.	BP1002 $48LD_{50}$ = 15 ppm		
Lobster	*Homarus gammarus*	LABORATORY	various emulsifiers	~4 ppm	48 hrs.	BP1002 $24LD_{50}$ = 20 ppm		
Barnacles	*Elminius modestus*	LABORATORY	1-100 ppm BP1002	0-20 ppm	48 hrs.	100% mortality with 100 ppm; 5 ppm shows sublethal effect	1	
			100 ppm film of Kuwait	0.1 ppm	24 hrs.	some inhibition of cirral beat		
Lobsters	*Homarus americanus*	LABORATORY	Bunker C and various dispersants		7-14 days	4 day LD_{50} for Bunker C > 10,000 ppm	1	lobster fishery of Chedabucto Bay not damaged by Arrow spill; lobsters considered very resistant
Barnacles	*Balanus balanoides*	LABORATORY	BP 1002	2 ppm		100% survival at 10 ppm	1	
Hermit Crab	*Eupagurus bernhardus*	LABORATORY	BP 1002	1 ppm		96 hrs. LD_{50} = 5 ppm		

SUMMARY OF TOXIC EFFECTS OF OIL ON MARINE BENTHIC CRUSTACEANS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Crab	*Carcinus maenas*	LABORATORY	BP 1002	6 ppm		96 LD_{50} = 30 ppm		
Crab	*Cancer pagures*	LABORATORY	BP 1002	2 ppm		24LD_{50} = 10 ppm	1	
Shrimp	*Crangon vulgaris*	LABORATORY	BP 1002	4 ppm		24LD_{50} = 2 ppm		
		LABORATORY	BP 1002	5 ppm		24LD_{50} = 25 ppm		
Hermit crab	*Diogenes pugilator*	LABORATORY	BP 1002	5 ppm		24LD_{50} = 25 ppm		
Barnacle	*Balanus balanoides*	LABORATORY	Crude oil	2 ppm		2% is toxic	1	
Many species		FIELD	Kuwait BP 1002				1	many field experiments and data which is difficult to summarize; data indicates little toxic response of most species to weathered kuwait.
Opossum shrimp	*Neomysis awatschensis*	STATIC BIOASSAY	#2 Diesel	0.112 ml/ℓ		48 hr. LC50	28	salinity 25‰
Subtidal amphipod	*Anisogammaris* Sp.	STATIC BIOASSAY	#2 Diesel	0.100 ml/ℓ		48 hr. LC50	28	salinity 30‰
Hairy Shore Crabs	*Hemigrapsus oregonensis*	STATIC BIOASSAY	#2 Diesel	3.00 ml/ℓ		48 hr. LC50	28	salinity 30‰

SUMMARY OF TOXIC EFFECTS OF OIL ON MARINE BENTHIC CRUSTACEANS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Barnacle	*Balanus balanoides*	LABORATORY	Diesel			toxic	29	initial sub-letnal response retarded cirral activity
Lobster	*Homarus americanus*	STATIC "BIOASSAY" SUBLETHAL	La Rosa crude oil 1% 100,000	17 µg/ℓ		depressed appetite & chemical excitability & increased time to find food	30	
Crab	*Pachygrapsus crassipes*	SUBLETHAL BIOASSAY	Methyl Ether Extract of crude oils			inhibits the feeding and sex hormone response	31	cited from Atema & Stein (1974)
Tanner Crabs	*Chionoectes bairdi*	STATIC BIOASSAYS	Prudhoe Bay crude	0.56 ml/ℓ 0.32 ml/ℓ		48 hr. TLM	32	molting success decreased w/increasing exp. to oil - newly molted crabs autotomized limbs during exposure to oil
Barnacles	*Balanus balanoides*	FIELD (spill) Observations	Bunker C			no unusual mortalities detected & subsequent larval settlement successful	33	Arrow incident

SUMMARY OF TOXIC EFFECTS OF OILS ON LARVAE AND EGGS OF MARINE ORGANISMS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Plaice	*Rhombus maeoticus*	LABORATORY	"oil" 10^{-4} -10^{-5} ml/ℓ			40 to 100% hatched pre-larvae perished	1	no information on experimental methods
Barnacle	*Balanus* Sp.					Larvae 100 times more sensitive than adults	1	no information on experimental methods
Cod and Flounder		LABORATORY	Bunker C film - 100 ppm	~0	96 hrs.	35% pulled in stagnant water, not affected in running water	1	no information on experimental methods
Black Sea Turbot		LABORATORY	10-100 ppm dispersion of Russian crude	0.01 - 1 ppm	2-3 days	100% eggs killed	1	no information on experimental methods
Herring		LABORATORY	10^3 and $2x10^4$ ppm film		2.5-3.5 days	100% eggs killed	1	no information on experimental methods
Cod	*Gadus morrhua*	LABORATORY	extract of Venezuelan oil in water 10^4 ppm 10^2 ppm extracts of Iranian crude 10^4 ppm 10^3 ppm 10^2 ppm control	 0.10 ppm 0.1 ppm 10 ppm 1 ppm 0.1 ppm	100 hrs.	40% higher mortality than control 10-20% increase in mortality 99% killed 63% killed 33% killed 21% killed	1	Libyan (high paraffin content) did not cause increases in mortality; 10 day old larvae less sensitive

SUMMARY OF TOXIC EFFECTS OF OILS ON LARVAE AND EGGS OF MARINE ORGANISMS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Cod	*Gadus morrhua*	LABORATORY	extracts of Iranian crude in water 10^4 ppm 10^3 ppm 10^2 ppm 10^3 plus 10-100 ppm Corexit 7664 10-100 ppm Corexit 7664	 10 ppm 1 ppm 0.1 ppm control 100-1000 ppm ~0	1-10 days 4.2 days 8.4 days 14 days 14 days 3 to 6 hrs. no effect	time to death for larvae exposed for 1 day	1	young larvae less resistant than embryo; Herring less resistant; Plaice more resistant; Libyan crude affected larvae more than embryos.
Plaice	*Pleuronectes platessa*	LABORATORY	0-10 ppm BP1002	0-2 ppm	1-30 days	10 ppm BP 1002 killed 100%; 2.5 ppm BP1002 reduced survival by 50%	1	see original article for considerable more detail; some mortality delayed due to effects on feeding and larval development
Barnacle	*Elminius modestus*	LABORATORY	0-100 ppm BP1002 1000 ppm Kuwait	0-20 ppm 1 ppm	various	0-3 ppm BP1002 increase mortality some reduction of activity	1	original article contains much more data on other dispersants and other tests; adults resistant up to 100 ppm BP1002
Filchard	*Sardina pilchardus*	Torrey Canyon Incident	Kuwait and emulsifiers			50-90% of eggs in plankton tows dead	1	
Lobsters	*Homarus americanus*	LABORATORY	0.001 - 0.1 ml/ℓ Venezuelan crude	(0.01-1 ppm)	24-96 hrs.	96LD$_{50}$= 0.03 002 ml/ℓ	1	0.001 ml/ℓ had little effect; 0.1 ml/ℓ very toxic

SUMMARY OF TOXIC EFFECTS OF OILS ON LARVAE AND EGGS OF MARINE ORGANISMS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Sea Urchin	*Strongylocentrotus purpuratus*	LABORATORY	extracts of 25 ml crude and Bunker C oils in 500 ml sea water 6.25% - 50% dilutions	(0.1-1 ppm)		fertilization not affected; lowest dilutions interfere with fertilized egg development	1	Urchins generally very sensitive
Polychaete	*Sabellaria spinulosa*	LABORATORY	0.5 - 1 ppm BP1002	0.1 - 0.2 ppm	several hours to several days	1 ppm caused 100% mortality; 0.5 ppm caused abnormal development	1	death definitely due to kerosene solvent in BP1002
Crustaceans	*several*	LABORATORY	1 - 10 ppm BP1002	0.2 - 2 ppm		1 ppm BP 1002 lethal	1	larvae 10-100 times as sensitive as adults
Oysters	*Crassostrea gigas*	LABORATORY	various detergents 0-3 ppm	0 - 0.5 ppm	24 hrs.	3 ppm of all detergents toxic	1	also similar results for many other marine invertebrate larvae
Limpet Veliger Larvae	*Acmaea scutum*	STATIC BIOASSAYS	#2 Diesel 0.5% slick in 50 ml beaker		48 hrs.	survival	34	
Tectibranch Veliger Larvae	*Haminoea virescens*	STATIC BIOASSAYS	#2 Diesel 0.5% slick in 50 ml beaker		31 hrs.	survival	34	

SUMMARY OF TOXIC EFFECTS OF OILS ON LARVAE AND EGGS OF MARINE ORGANISMS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Nudi-branch Veliger Larvae	*Melibe leonina*	STATIC BIOASSAYS	#2 Diesel 0.5% slick in 50 ml beaker		15 hrs.	survival	34	
Oyster Veliger Larvae	*Crassostrea gigas*	STATIC BIOASSAYS	#2 Diesel 0.5% slick in 50 ml beaker		24 hrs.	survival	34	
Chiton Trochophore Larvae	*Katharina tunicata*	STATIC BIOASSAYS	#2 Diesel 0.5% slick in 50 ml beaker		72 hrs.	survival	34	
Acorn Barnacle Nauplius	*Elminius modestus*	LABORATORY	17 Alcohols 5 Paraffins 6 Cycuc compounds 5 Aromatics Ethers Halogens Nitriles	saturated aqueus solutions		toxicity dec. w/inc. molecular size & assymmetry within homologous series cycuc to aromatics 5-9 x as toxic as respective straight chain compounds polar substituents enhanced toxicity	35	

SUMMARY OF TOXIC EFFECTS OF OILS ON LARVAE AND EGGS OF MARINE ORGANISMS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Lobster (Larvae)	*Homarus americanus*	LABORATORY	Venezuelan crude oil			-mortalities occurred when larvae molted -sublethal conc. delayed molting up to 30 days	36	
Plank-tonic Mouuscan Larvae		FIELD OBSERVATIONS	floating oil			observed direct mortalities in field situation	37	
Oyster Larvae	*Crassostrea virginica*	LABORATORY	A film of crude oil just sufficient to cover surface			direct mortality within 1 hr @ 24°C	38	
Oyster Larvae (spat)	*Crassostrea virginica*	FIELD EXPERIMENTS	Louisiana crude			no effect of oil on spatfall, spat survival or spat growth	39	
Oyster Larvae (spat)	*Crassostrea virginica*	FIELD EXPERIMENTS	Louisiana crude			spat settled on oil soaked wood	40	

SUMMARY OF TOXIC EFFECTS OF OILS ON LARVAE AND EGGS OF MARINE ORGANISMS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Pacific Oyster Larvae	*Crassostrea gigas (larvae)*	STATIC 1ℓ BIOASSAYS	Benzene, Toluene, Xylenes	3.1-3.6 mg/ℓ		first inhibition of normal larval development	41	
Pacific Oyster Larvae	*Crassostrea gigas (larvae)*	STATIC 1ℓ BIOASSAYS	Alaskan crude	1.0 ml	48 hrs.	50% mortality & 50% abnormal development	41	
Pacific Oyster Larvae	*Crassostrea gigas (larvae)*	STATIC 1ℓ BIOASSAYS	Cyclooctane Naphthalene Isopropyl benzene	0.103 ml/ℓ 0.110 ml/ℓ 0.135 ml/ℓ		EMD 50 (% ecol. mortality)	41	solubility (mg/ℓ) 7.9+1.8 32 - 34 50±5
Pacific Oyster Larvae	*Crassostrea gigas (larvae)*	STATIC 1ℓ BIOASSAYS	O-xylene Toluene Ethyl benzene	0.192 ml/ℓ 0.199 ml/ℓ 0.373 ml/ℓ		EMD 50 (% ecol. mortality)	41	175-204 515±17 152-208
Pacific Oyster Larvae	*Crassostrea gigas (larvae)*	STATIC 1ℓ BIOASSAYS	Benzene P-xylene Cyclohexene	0.429 ml/ℓ 0.678 ml/ℓ 0.691 ml/ℓ		EMD 50 (% ecol. mortality)	41	1740-2220 198-200 213±10
Pacific Oyster Larvae	*Crassostrea gigas (larvae)*	STATIC 1ℓ BIOASSAYS	O-, M- P- Xylenes Mixed	0.693		EMD 50 (% ecol. mortality)	41	
Pacific Oyster Larvae	*Crassostrea gigas (larvae)*	STATIC 1ℓ BIOASSAYS	Cyclohexane Cyclopentane	2.120 4.540		EMD 50 (% ecol. mortality)	41	55±2.3 156±9
Oysters	*Crassostrea angulata & C. gigas*	STATIC BIOASSAYS	Venezuelan crude & #1 fuel oil	~1000 ppm	6 hrs.	"sign." mortalities 25-32%	42	eggs fertilized by sperm previously exposed to hydrocarbons exhibit inc. mortality

INCORPORATION OF OIL INTO TISSUES OF MARINE ORGANISMS

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Clam	*Mercenaria mercenaria*	CHRONICALLY POL-LUTED BAY		26-163 μg/g wet weight			43	
Am. Oyst-ers	*Crassostrea virginica*	HEAVILY POLLUTED BAY		236 μg/g wet weight			44	
Scallops	*Placopecten magellanicus*	Arrow spill of 108,000 bbl of Bunker C fuel oil		hydrocarbons in mantle, digestive gland, adductor muscle & gonad			45	
Peri-winkles	*Littorina littorea*	Arrow spill of 108,000 bbl of Bunker C fuel oil		27-600 μg/g wet weight			45	
Mussels	*Modiolus modiolus*	Arrow spill of 108,000 bbl of Bunker C fuel oil		21-372 μg/g wet weight			45	
Mussels	*Mytilus* Sp.	LABORATORY	Residual fuel oil	77-103 μg/g wet weight			46	
Peri-winkles	*Littorina littorea*	LABORATORY	Residual fuel oil	57-231 μg/g wet weight			46	
Softshell Clam	*Mya arenaria*	LABORATORY	Residual fuel oil	87 μg/g wet weight			46	
Bay Mussel	*Mytilus edulis*	LABORATORY	Labeled hydrocar-bons	1-400 g/mussel 14_c Heptadecane 14_c Toluene 14_c Naphthalene 3_n 3,4 Benzoptrene			47	retained after cleansing in clear sea water

INCORPORATION OF OIL INTO TISSUES OF MARINE ORGANISMS

ORGANISM: COMMON NAME (1)	ORGANISM: SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Am. Oyster	*Crassostrea virginica*	FIELD Samples from Mass. (Buzzards Bay) spill	#2 fuel oil	incorporated into general lipid pool			48	organisms cleaned (after 6 mo.) only of straight - and branched - chain hydrocarbons aromatics retained
Scallops	*Aequipecten irradians*			incorporated into general lipid pool			48	
Softshell Clams	*Mya arenaria*			incorporated into general lipid pool			48	
Quanaugs	*Mercenaria mercenaria*			incorporated into general lipid pool			48	
Mollusks		FIELD samples		3,4 - Benzopyrene 90 μg/kg dry wt. (ppb)			49	cited in Legore (1974) known carcinogen
Am. Oyster	*Crassostrea virginica*	FIELD samples		3,4 - Benzopyrene 2-6 μg/kg dry wt. (ppb)			49	cited in Legore (1974) known carcinogen
Mussels	*Mytilus edulis* (*Greenland*)	FIELD samples		3,4 - Benzopyrene 55 μg/kg dry wt. (ppb)			49	cited in Legore (1974) known carcinogen
Oysters	*Ostrea* Sp. *lurida*	FIELD samples (France)		3,4 - Benzopyrene "traces"			50	known carcinogen cited in Legore (1974)
Am. Oyster	*Crassostrea virginica*	FIELD samples		retained higher content of aromatics			51	
Am. Oyster	*Crassostrea virginica*	FIELD samples		retained aromatic fractions longer than saturated chains			52	De-puration achieved in 30 days

REFERENCES

(1) President's Council on Environmental Quality, *OUTER CONTINENTAL SHELF OIL AND GAS--AN ENVIRONMENTAL ASSESSMENT*, April, 1974.

(2) Thomas, M. L. H., "Effects of Bunker C Oil on Intertidal and Lagoonal Biota in Chedabucto Bay, Nova Scotia," *J. FISH. RES. BD. CANADA*, 30:83-90, 1973.

(3) LaRoche, G., R. Gisler, and C. M. Tarzwell, "Bioassay Procedures for Oil and Oil Dispersant Evaluation," *J. WATER POLLUT. CONTROL FED.*, 42:1982-1988, 1970.

(4) Galtsoff, P.S.

(5) Morrow, J. E., "Oil-induced Mortalities in Juvenile Coho and Sockeye Salmon," *J. MAR. RES.*, 31(3):135-143, 1973.

(6) Cardwell, R.D., *ACUTE TOXICITY OF NO. 2 DIESEL OIL TO SELECTED SPECIES OF MARINE INVERTEBRATES, MARINE SCULPENS AND JUVENILE SALMON*, Ph. D. Dissertation, Univ. of Wash. College of Fisheries, 124 pp, 1973.

(7) Thomas, M. L. H., "Effects of Bunker C Oil on Intertidal and Lagoonal Biota in Chedabucto Bay, Nova Scotia," *J. FISH. RES. BD. CANADA*, 30:83-90, 1973.

(8) Hokanson, K. E. F. and L. L. Smith, "Some Factors Influencing Toxicity of Linear Alkylate Sulfonate (LAS)," *TRANS. AMER. FISH. SOC.*, 100:1-12, 1971.

(9) Pickering, Q. H., and C. Henderson, "Acute Toxicity of Some Important Petrochemicals to Fish," *J. WAT. POLLUT. CONTROL FED.*, 38:1419-1429, 1966.

(10) Roberts, C. H., "Oil Pollution: The Effect of Oil Pollution Upon Certain Forms of Aquatic Life and Experiments Upon the Rate of Absorbtion, Through Films of Various Fuel Oils, of Atmospheric Oxygen By Sea Water," *J. CONS. PERM. INT. EXPLOR. MER.*, 1:245-275, 1926.

(11) Cardwell, R. D., *ACUTE TOXICITY OF NO. 2 DIESEL OIL TO SELECTED SPECIES OF MARINE INVERTEBRATES, MARINE SCULPENS AND JUVENILE SALMON*, Ph. D. Dissertation, Univ. of Wash. College of Fisheries, 124 pp, 1973.

(12) Griffith, D. de G., "Toxicity of Crude Oil and Detergents to Two Species of Edible Molluscs Under Artificial Tidal Conditions," IN: Report of the FAO Technical Conference on Marine Pollution and Its Effects on Living Resources and Fishing, *FAO FISH. REP.*, No. 99. FIRM/R99(En), 188 pp, 1971.

(13) Dicks, B., "Some Effects of Kuwait Crude Oil on the Limpet, *Patella vulgata*," *ENVIRON. POLLUT.*, 58219-58229, 1973.

(14) Jacobson, S. M. and D. B. Boylan, "Effects of Sea Water Soluble Fraction of Kerosene on Chemotaxis in a Marine Snail, *Nassarius obsoletus*," *NATURE* (London), 241:213-225, 1973.

(15) Thomas, M. L. H., "Effects of Bunker C Oil on Intertidal and Lagoonal Biota in Chedabucto Bay, Nova Scotia," *J. FISH. RES. BD. CANADA*, 30:83-90, 1973.

(16) Hargrave, B. T. and C. D. Newcombe, "Crawling and Respiration as Indices of Sublethal Effects of Oil and a Dispersant on an Intertidal Snail, *Littorina Littorea*," *J. FISH. RES. BD. CANADA*, 30(1):1789-1792, 1973.

(17) Cardwell, R. D., *ACUTE TOXICITY OF NO. 2 DIESEL OIL TO SELECTED SPECIES OF MARINE INVERTEBRATES, MARINE SCULPENS AND JUVENILE SALMON*, Ph. D. Dissertation, Univ. of Wash. College of Fisheries, 124 pp, 1973.

(18) Galtsoff, P. S.

(19) Griffith, D. de G., "Toxicity of Crude Oil and Detergents to Two Species of Edible Molluscs Under Artificial Tidal Conditions," IN: Report of the FAO Technical Conference on Marine Pollution and Its Effects on Living Resources and Fishing, *FAO FISH. REP.*, No. 99. FIRM/R99(En), 188 pp, 1971.

(20) Mencel, R. W. and S. H. Hopkins, *REPORT ON EXPERIMENTS TO TEST THE EFFECTS OF OIL BRINE OR "BLEEDWATER" ON OYSTERS AT LAKE BARRE OIL FIELD*, Texas A & M Res. Foundation, Project Nine Report, 252 pp, 1951.

(21) Mitchell, P. H., "The Effect of Water-Gas Tar on Oysters, *BULL. U. S. BUR. FISH.*, 32:199-206, 1912.

(22) Leenhardt, H., *THE EFFECT OF FUEL OIL ON SHELLFISH*, (In French), Cons. Perm. Int. Explor. Mer, Rapp. Proces-Verbanx Des Reunions, 35:56-68, 1925.

(23) Thomas, M. L. H., "Effects of Bunker C Oil on Intertidal and Lagoonal Biota in Chedabucto Bay, Nova Scotia," *J. FISH. RES. BD. CANADA*, 30:83-90, 1973.

(24) Clark, R. D. Jr., and J. S. Finley, "Paraffin Hydrocarbon Patterns in Petroleum-Polluted Mussels," *MAR. POLL. BULL.*, 4(3):172-176, 1973.

(25) Conover, R. J., "Some Relations Between Zooplankton and Bunker C Oil in Chedabucto Bay Following the Wreck of the Tanker ARROW," *J. FISH. RES. BD. CANADA*, 28:1227-1330, 1971.

(26) Galtsoff, P. S.

(27) George, J. D., "The Effects of Pollution by Oil and Oil-Dispersants on the Common Intertidal Polychaetes, *Cirrifornia tentaculata* and *Cirratulus cirratus*," *J. APPL. ECOL.*, 8:411-420, 1971.

(28) Cardwell, R. D., *ACUTE TOXICITY OF NO. 2 DIESEL OIL TO SELECTED SPECIES OF MARINE INVERTEBRATES, MARINE SCULPENS AND JUVENILE SALMON*, Ph. D. Dissertation, Univ. of Wash. College of Fisheries, 124 pp, 1973.

(29) Galtsoff, P. S.

(30) Atema J. and L. S. Stein, "Effects of Crude Oil on the Feeding Behavior of the Lobster, *Homarus americanus*," *ENVIRON. POLLUT.*, 6(1974): 77-86, 1974.

(31) Kittredge, J. S., "Effects of the Water Soluble Components of Oil Pollution on Chemoreception by Crabs," *FISH. BULL. CALIF.*, (in press).

(32) Arctic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, prepared for the Department of the Army, Alaska District, Corps of Engineers, February, 1974.

(33) Thomas, M. L. H., "Effects of Bunker C Oil on Intertidal and Lagoonal Biota in Chedabucto Bay, Nova Scotia," *J. FISH. RES. BD. CANADA*, 30:83-90, 1973.

(34) Chia, F., "Influence of Crude Oil, Derivitives and Dispersants on Larvae," *MARINE POLL. BULL.*, 4(1):9-13, 1973.

(35) Crisp, D. J., A. O. Christie, and A. F. G. Ghobashy, "Narcotic and Toxic Action of Organic Compounds on Barnacle Larvae," *COMP. BIOCHEM. PHYSIOL.*, 22:629-649, 1967.

(36) Wells, P. G., "Influence of Venezuelan Crude Oil on Lobster Larvae," *MAR. POLLUT. BULL.*, 3:105-106, 1972.

(37) Elmhirst, R., "Investigations on the Effect of Oil Tanker Discharge," Ann. Rep., *SCOTTISH MAR. BIOL. ASSN.*, 1922. (Cited from Reference No. 4.)

(38) Nelson, T. C., "Some Aspects of Pollution as Affecting Oyster Propagation," *AMER. J. PUBLIC HEALTH.*, 11(6):498-501, 1921.

(39) Mackin, J. G., Preliminary Report on Oyster Spraying Experiment. Texas A & M Res. Found. Project Nine Report, 1947. (Also three

additional reports in 1948 for same project on First, Second and Third Spraying Experiments by same author.)

(40) Mackin, J. G., *A STUDY OF THE EFFECTS ON OYSTERS OF A HEAVY SURFACE-WATER LAYER OF CRUDE OIL*, Texas A & M Res. Found. Project Nine Report, 16 pp, 1948.

(41) Legore, R. S., *THE EFFECT OF ALASKAN CRUDE OIL AND SELECTED HYDROCARBON COMPOUNDS ON EMBRYONIC DEVELOPMENT OF THE PACIFIC OYSTER, Crassostrea gigas*, Ph. D Dissertation, Univ. of Wash., College of Fisheries, 188 pp, 1974.

(42) Renzoni, A., "Influence of Crude Oil, Derivitives, and Dispersants on Larvae," *MARINE POLLUT. BULL.*, 4(1):9-13, 1973.

(43) Farrington, J. W. and J. G. Guinn, "Petroleum Hydrocarbons in Narragansett Bay. I. Survey of Hydrocarbons in Sediments and Clams (*Mercenaria mercenaria*)," *ESTUARINE COASTAL MAR. SCI.*, 1:71-19, 1973.

(44) Ehrhardt, M. "Petroleum Hydrocarbons in Oysters from Galveston Bay," *ENVIRON. POLLUT.*, 3(4):257-271, 1972.

(45) Scarratt, D. J. and V. Zitko, "Bunker C Oil in Sediments and Benthic Animals From Shallow Depths in Chedabucto Bay, N. S.," *J. FISH. RES. BD. CANADA*, 29(a):1347-1350, 1972.

(46) Zitko, V., "Determination of Residual Fuel Oil Contamination of Aquatic Animals," *BULL. ENVIRON. CONTAM. TOXICOL.*, 5(6):559-564, 1970.

(47) Lee, R. F., R. Sanerheber, and A. A. Benson, "Petroleum Hydrocarbons: Uptake and Discharge by the Marine Mussel, *Mytilus edulus*," *SCIENCE*, 177(4046):344-346, 1972.

(48) Blumer, M., G. Sonza, and J. Sass, "Hydrocarbon Pollution of Edible Shellfish by an Oil Spill," *MARINE BIOL.*, 5(3):195-202, 1970.

(49) Michael, D. R., and J. Suess, "Presence of Polynuclear Aromatic Hydrocarbons in Coastal Waters and the Possible Health Consequences, *REV. INTERNAT. OCEANOGR. MED.*, 18-19:181-190, 1970.

(50) Tendron, G., "Contamination of Marine Flora and Fauna by Oil and the Biological Consequences of the TORREY CANYON Incident," In: *OIL POLLUTION OF THE SEA*, Warren and Son, Ltd, Winchester, G.B.: The Wykeham Press, 1968.

(51) Stegeman, J. J., and J. M. Teal, "Accumulation, Release, and Retention of Petroleum Hydrocarbons by the Oyster, *Crassostrea virginica*," *MARINE BIOL.*, 22(1):37-44, 1973.

(52) Anderson, R. D., *EFFECTS OF PETROLEUM HYDROCARBONS ON THE PHYSIOLOGY OF THE AMERICAN OYSTER, Crassostrea virginica gmelin*, Ph. D Dissertation, Texas A & M Univ., 146 pp, 1973.

DISPERSANT IMPACTS ON MARINE FLORA/FAUNA

ORGANISM: COMMON NAME (1)	ORGANISM: SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Peri-winkles	*Littorina littorea*	STATIC BIOASSAY (dipped in solvent emulsifiers & then cleaned)			after 7 days	50-100% because moribund & extended out of shells	1	
Oysters	*Ostrea edulis* *Crassostrea angulata*	STATIC BIOASSAY	"Polyclens" & "Slix"	10 ppm 32 ppm 100 ppm 320 ppm	24 hr. treatment	cleaned & held 7 days resistant	1	
Mussels	*Mytilus edulis*	STATIC BIOASSAY	"Polyclens" & "Slix"	10 ppm 32 ppm 100 ppm 320 ppm		no derately resistant	1	
Cockles	*Cardium edule*	STATIC BIOASSAY	"Polyclens" & "Slix"	10 ppm 32 ppm 100 ppm 320 ppm		50% mort. @ 32-100 ppm "Polyclens" & 10-32 ppm "Slix"	1	
Shrimp	*Pandalus montagui* *Crangon crangon*	STATIC BIOASSAY	2 chemical solvent/ emulsifiers (BP1002)		48 hrs.	sensitive	1	15°C
Shore Crab	*Carcinus maenas*	STATIC BIOASSAY			48 hrs.	mod. sensi-tive	1	
Cockle	*Cardium edule*	STATIC BIOASSAY			48 hrs.	less sensi-tive	1	
Flatfish	*Solea solea*	STATIC BIOASSAY	BP 1002	50 ppm	24 hrs.	LC50 = 5ppm	1	72 hr. aged sol. did not cause morts.

DISPERSANT IMPACTS ON MARINE FLORA/FAUNA

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUSSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (5)
Polychaete Larvae	*Sabellaria spinulosa*	STATIC BIOASSAY	BP 1002			mortality after some weeks	2	
Razor Shell	*Ensis siliqua*	LABORATORY	crude oil/solvent/ emulsifier			most sensi-tive	3	oil/emulsifier mixture less toxic
Hermit Crab	*Diogenes pugilator*	LABORATORY	crude oil/solvent/ emulsifier			least sensi-tive	3	oil/emulsifier mixture less toxic
Starfish	*Asterias rubens*	LABORATORY	crude oil/solvent/ emulsifier			least sen-sitive	3	oil/emulsifier mixture less toxic
Shore Crabs (Adult & Larvae)	*Carcinus maenas*	LABORATORY	crude oil/solvent/ emulsifier			smaller organisms more sus-ceptible than larger fotems	4	solvent fraction considerably more toxic than either the stabilizer or the surfactant
Brown Shrimp	*Crangon crangon*	LABORATORY	crude oil/solvent/ emulsifier			smaller organisms more sus-ceptible than larger fotems	4	solvent fraction considerably more toxic than either the stabilizer or the surfactant
Copepod	*Calanus finmarchicus*	LABORATORY	(dispersant)			more resis-tant	5	
Copepod	*Acartia clausi*	LABORATORY				less resis-tant	5	

DISPERSANT IMPACTS ON MARINE FLORA/FAUNA

ORGANISM								
COMMON NAME (1)	SCIENTIFIC NAME (2)	EXPERIMENT TYPE (3)	SUBSTANCE AND REPORTED AMOUNT (4)	ESTIMATED HYDRO-CARBONS IN SOLUTION (5)	DURATION (6)	RESPONSE (7)	REFERENCE (8)	REMARKS (9)
Wrack, Intertid-al Brown Alga	*Fucus gardneri*	SPILL OBSERVATION	heavy fuel oil w/no paraffin hydrocar-bons	long term, low level exposure	15 mos.	no visible contamina-tion thru fronds were dull in color & flaclid	6	
Red Alga	*Prionitis lanceolata*	LABORATORY	lighter oils - gaso-lines & diesel oil			bleached plant - fractions entering cellular matrix & extracting pigment - i.e. dissol-ving caroten-oids	6	
Red Alga	*Prionitis lanceolata*	LABORATORY	crudes, fuel oils - heavier oils				6	
Shore Crabs	*Hemigrapsus nudus*	LABORATORY	Paraffin				7	quoted in Clark (1973)

DISPERSANT IMPACTS REFERENCES

(1) Shelton, R. G. J., "Dispersants Toxicity Test Procedures," In: American Petroleum Institute, Environmental Protection Agency, and U. S. Coast Guard, *PROCEEDINGS OF JOINT CONFERENCE ON PREVENTION AND CONTROL OF OIL SPILLS, 1969.*

(2) Wilson, D. P., "Longterm Effects of Low Concentrations of an Oil Spill Remover ("detergent")," (Studies with the Larvae of *Sabellaria spinulosa.*), *J. MARINE BIOL. ASSOC. UNITED KINGDOM*, Vol. 48, pp. 177-182, 1968.

(3) Corner, E. D. S., A. J. Southward and E. C. Southward, "Toxicity of Oil-Spill Removers to Marine Life: An Assessment Using the Barnacle *Elminius modestus*," *J. MARINE BIOL. ASSOC.*, United Kingdom, Vol. 48, pp. 29-47, 1968.

(4) Portmann, J. E. and P. M. Connor, "The Toxicity of Oil Spill Removers to Some Species of Fish and Shellfish," *MARINE BIOL.*, Vol. 1, No. 4, pp. 322-329, 1968.

(5) Smith, J. E., Editor, "TORREY CANYON Pollution and Marine Life," *A REPORT BY THE PLYMOUTH LABORATORY OF THE MARINE BIOLOGICAL ASSOCIATION OF THE UNITED KINGDOM*, Cambridge Univ. Press, xiv + 196 p, 1968.

APPENDIX C

FAUNAL SENSITIVITY PERIODS BY LOCATION

YAKUTAT FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY   ------ MODERATE SENSITIVITY   ____ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bear					concentrations on streams and beach grass areas							
Black Bear [1]					concentrations on streams and beach grass areas							
Large Land Carnivores												
Moose	concentrations on willow flats			calving on willow flats							concentrated in willow flats	
Blacktail Deer	concentrated along beaches				fawning							concentrated along beaches
Aquatic Furbearers	general vulnerability in freshwater areas				birth and rearing of young		general vulnerability in freshwater areas					
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal	general vulnerability in marine shore areas				whelping and rearing of young		general vulnerability in marine shore areas					
Sea Lion	general vulnerability in marine shore areas				whelping and rearing of young		general vulnerability in marine shore areas					
Sea Otter	low population - building - highly susceptible to oil spill - whelp and breed all seasons											
Northern Fur Seal	dispersal throughout area									dispersal throughout area		
Whales and Dolphins		many species in migration										
AVIFAUNA												
Ducks	heavy overwintering population			Spring migration		breeding and brooding			Fall migration			overwintering
Geese [2]	overwintering geese			...ing migration		breeding and brooding			Fall migration			overwintering
Swans [3]	overwintering swans			Spring migration		breeding and brooding			Fall migration			overwintering
Seabirds	year-long residents and migrants - highly vulnerable at all seasons											
Shorebirds and Cranes				migration			breeding and brooding			migration		
Upland Game Birds												
Raptors	Eagles resident year long			breeding and brooding								
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

[1] Rare Glacier Bear - thus this classification.

[2] Includes Vancouver race (rare).

[3] Some believed to be trumpeters (rare).

VALDEZ HARBOR FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY _____ MODERATE SENSITIVITY _____ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bear[1]												
Black Bear[2]						concentrations on streams and grass flats						
Wolves and Wolverines												
Moose												
Aquatic Furbearers[3]												
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal[4]												
Sea Lion												
Fur Seal[5]												
Whales and Porpoises[5]												
AVIFAUNA												
Ducks	overwintering			Spring migration					Fall migration			overwintering birds
Geese				Spring migration					Fall migration			
Swans				Spring migration					Fall migration			
Seabirds				year-long residents and migrants - vulnerable all seasons								
Shore Birds and Cranes				migration					migration			
Upland Game Birds												
Raptors	Eagles year long resident			Eagle breeding and brooding					Eagles year long			
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

[1] Very minor abundance.

[2] A few of the rare glacier color phase.

[3] Minor abundance, limited habitat.

[4] Relatively low abundance infrequent occurrence.

[5] Infrequent occurrence.

VALDEZ NARROWS FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ______ MODERATE SENSITIVITY ______ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bear						concentrations on streams and beach grass flats						
Black Bear					concentrations on streams and beach grass flats - including some glacier phase animals							
Large Land Carnivores												
Moose[1]												
Blacktail Deer	Winter beach foraging				fawning							beach foraging
Aquatic Furbearers	general high vulnerability in freshwater areas					birth and rearing of young		general high vulnerability in freshwater areas				
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal	general vulnerability in marine shore areas					whelping and rearing of young		general vulnerability in marine shore areas				
Sea Lion	general vulnerability in marine shore areas				whelping and rearing of young			general vulnerability in marine shore areas				
Sea Otter					populations increasing - whelp and breed throughout year. Highly susceptible to oil spills.							
Fur Seal						highly susceptible to oil pollution						
Whales and Porpoises						many species in migration						
AVIFAUNA												
Ducks[2]	overwintering			Spring migration			breeding and rearing			Fall migration		overwintering
Geese[2]	overwintering			Spring migration			breeding and rearing[3]			Fall migration		overwintering
Swans[2]	overwintering			Spring migration			breeding and rearing[3]			Fall migration		overwintering
Seabirds	some year-long populations			Spring migration			breeding and rearing[3]		Fall migration			overwintering
Shorebirds and Cranes					Spring migration				Fall migration			
Upland Game Birds												
Raptors	year-long Eagle population			breeding and brooding Eagles					year-long Eagle population			
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

[1]Only contact head of Valdez Harbor.

[2]Heavy waterfowl use - numerous intertidal and estuarine areas - used as brooding and migration habitat.

[3]Two rare species - dusky and Vancouver Canada Geese

DRIFT RIVER FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ______ MODERATE SENSITIVITY ______ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bear						concentrations on streams and beaches						
Black Bear						concentrations on streams and beaches						
Large Land Carnivores												
Moose	winter concentrations on willow flats			calving on willow flats								Winter concentrations
Caribou [1]												
Aquatic Furbearers	vulnerable in freshwater areas				birth-rearing of young			vulnerable in freshwater areas				
MARINE MAMMALS												
Harbor Seal	general vulnerability in marine inshore areas				whelping and rearing of young			general vulnerability in marine inshore areas				
Sea Lion					whelping and rearing of young							
Sea Otter	low population - growing - highly vulnerable to spill at all seasons											
Whales and Porpoises				Beluga whales								
Fur Seal	sparsely dispersed throughout									sparsely dispersed throughout highly susceptible to oil pollution		
AVIFAUNA												
Ducks				Spring migration		breeding and brooding			Fall migration			
Geese				Spring migration		breeding and brooding			Fall migration			
Swans				Spring migration		breeding and brooding			Fall migration			
Seabirds				Spring migration		breeding and brooding			Fall migration			
Shorebirds and Cranes					Spring migration		breeding and brooding		Fall migration			
Upland Game Birds												
Raptors				Eagle breeding and rearing								
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

[1] Possible impact from shore-based cleanup.

PORT GRAHAM FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ------ MODERATE SENSITIVITY ______ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bear												
Black Bear					concentrations on streams - grass flats							
Large Land Carnivores												
Moose	concen[illegible] winter use											
Aquatic Furbearers	vulnerable in freshwater areas				birth and rearing of young			vulnerable in freshwater areas				
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal	vulnerable in marine inshore areas				whelping and rearing of young			vulnerable in marine inshore areas				
Sea Lion	vulnerable in marine inshore areas				whelping and rearing of young			vulnerable in marine inshore areas				
Sea Otter	whelp and breed all seasons - highly susceptible to oil pollution - population increasing											
Fur Seal[1]	general light dispersion throughout area											
Whales and Porpoises[2]										general light dispersion throughout area		
AVIFAUNA												
Ducks[3]	major wintering area			Spring migration		breeding and rearing of young - Fall migration					major wintering area	
Geese	some overwintering birds			Spring migration		breeding and rearing of young		Fall migration			major wintering area	
Swans				Spring migration		breeding and rearing of young			Fall migration			
Seabirds	overwintering birds			Spring migration		breeding and rearing of young		Fall migration			overwintering	
Shorebirds and Cranes				Spring migration					Fall migration			
Upland Game Birds												
Raptors	year-long Bald Eagle population			breeding and rearing of young			year-long Bald Eagle population					
Other Terrestrial Birds												

SOURCE: A. V. Erickson, personal communication.

[1]Sensitive to oil pollution.

[2]A few Beluga whales but impact potential low.

[3]Sensitive year long.

KAMISHAK BAY FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ____ MODERATE SENSITIVITY ____ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bear							major concentrations on streams and grass flats					
Black Bear[1]												
Large Land Carnivores												
Moose[2]		wintering in lowland areas				calving on willow flats						wintering
Caribou												
Aquatic Furbearers			general vulnerability in freshwater environments			whelping and rearing of young				general vulnerability in freshwater environments		
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal		general vulnerability in nearshore marine environments				whelping and rearing of young				general vulnerability in nearshore marine environments		
Sea Lion		general vulnerability in nearshore marine environments				whelping and rearing of young				general vulnerability in nearshore marine environments		
Sea Otter		general vulnerability in nearshore marine environments				whelping and rearing of young				general vulnerability in nearshore marine environments		
Fur Seal			light dispersal through area, highly susceptible to oil pollution								general dispersal	
Whales and Porpoises						a number of species in migration						
AVIFAUNA												
Ducks		overwintering birds		Spring migration		breeding and brooding			Fall migration			overwintering birds
Geese				Spring migration		breeding and brooding				Fall migration		
Swans				Spring migration		breeding and brooding			Fall migration			
Seabirds		year-long residents		Spring migration		breeding and brooding			Fall migration		year-long residents	
Shorebirds and Cranes				Spring migration		breeders			Fall migration			
Upland Game Birds												
Raptors		year-long residents, migration			breeders				migration			
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

[1] Minor populations in this area.

[2] Low population but increasing extreme edge of range.

UNIMAK PASS FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ------ MODERATE SENSITIVITY ____ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bear					concentrated on streams and estuaries							
Caribou[1]					calving							
Large Carnivores												
Aquatic Furbearers	general vulnerability in freshwater areas				whelping and rearing of young			general vulnerability in freshwater areas				
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal	general vulnerability in marine inshore areas				whelping and rearing of young			general vulnerability in marine inshore areas				
Sea Lion[2]	general vulnerability in marine inshore areas				whelping and rearing of young			general vulnerability in marine inshore areas				
Sea Otter[3]	breed and whelp throughout year, highly susceptible to oil pollution											
Fur Seal[4]	general dispersal		Spring migration						Fall migration	general dispersal		
Whales and Porpoises				heavy migrant population of many species, including endangered forms								
AVIFAUNA												
Ducks	major wintering area for sea ducks			major migration, breeding, and rearing area				major migration area			major wintering area	
Geese	major wintering area for emperor goose			major migration area		breeding and rearing		major migration area			major wintering ground for emperor goose	
Swans				major migration area		breeding and rearing		major migration area				
Seabirds	large wintering populations			migration		/breeding and rearing/		migration			large wintering populations	
Shorebirds and Cranes				migration		breeding and rearing		migration				
Raptors	overwintering Aleutian Eagle			migration	breeding Eagles			migration			wintering Aleutian Eagle	
Upland Game Birds												
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

[1]Possible light conflict at all seasons associated with shore-based cleanup.

[2]Heavy population in unit.

[3]Heavy population throughout area.

[4]Highly vulnerable to oil pollution.

PORT MOLLER FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ...... MODERATE SENSITIVITY ____ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bears							concentrations on streams and grass flats					
Large Carnivores												
Moose		Winter concentrations in willow flats			calving on coast plain							Winter concentration
Caribou		wintering area			calving on coast plain							wintering area
Aquatic Furbearers		general vulnerability in freshwater areas				whelping and rearing of young				general vulnerability in freshwater areas		
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal		minor concentration				whelping and rearing of young				major concentration		minor concentration
Sea Lion			transient animals			possible whelping and rearing			transient animals			
Sea Otter	breed and whelp throughout year - highly susceptible to oil pollution											
Fur Seal		transient animals									transient animals	
Walrus				transient animals							transient animals	
Whales and Porpoises					local Beluga population - offshore migration other species							
AVIFAUNA												
Ducks	major wintering area for sea ducks			Spring migration			major breeding and brooding area		Fall migration		major wintering area	
Geese				Spring migration		major breeding and brooding area				Fall migration		
Swans				Spring migration		major breeding and brooding area				Fall migration		
Seabirds	overwintering forms			Spring migration		breeding and rearing				Fall migration		overwintering forms
Shorebirds and Cranes					Spring migration					Fall migration		
Raptors				migration		breeders		migration				
Upland Game Birds												
Other Terrestrial Birds												

SOURCE: A. J. Erickson, personal communication.

KVICHAK BAY FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ______ MODERATE SENSITIVITY ______ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bear					concentrations on streams and grass flats							
Large Carnivores												
Moose	Winter concentration along streams				calving on willow flats							Winter concentration
Caribou	Winter concentration subject to clean up efforts											Winter concentration
Aquatic Furbearers	general vulnerability in freshwater areas				whelping and rearing			as per Fall				
Other Mammals												
MARINE MAMMALS												
Harbor Seal	general vulnerability in marine inshore areas				whelping and rearing			as per Fall				
Sea Lion												
Whales and Porpoises [1]	general presence				concentrated in river mouths						general presence	
Fur Seal	low abundance - but are susceptible										low abundance	
Walrus						peripheral occurence locally						
Bearded Seal	peripheral occurrence											peripheral occurrence
AVIFAUNA												
Ducks	overwintering ducks			major migration area		breeding and rearing		heavy migration area				overwintering
Geese				major migration area		breeding and rearing			heavy migration area			
Swans				migration, breeding and rearing					migration			
Seabirds	overwintering			migration		breeding and rearing			migration			overwintering
Shorebirds				migration		breeding and rearing			migration			
Raptors				migration		breeding and rearing			migration			
Upland Game Birds												
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

[1] Beluga concentrations during salmon runs.

ST. MATTHEW FAUNAL SENSITIVITY PERIOD

...... LOW SENSITIVITY ------ MODERATE SENSITIVITY ——— HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Polar Bear	marginal occurrence											
Land Carnivore [1]			Possible influence on foods of sea origin									
Reindeer	potential range damage associated with cleanup				calving			potential range damage associated with cleanup				
Aquatic Furbearers	general vulnerability				breeding and care of young		general vulnerability					
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal						whelping and rearing young						
Fur Seal			limited presence					limited presence				
Walrus	present during ice period								present during packice period			
Ringed Seal	present during ice period								present during packice period			
Ribbon Seal	present during ice period								present during packice period			
Bearded Seal	present during ice period								present during packice period			
Whales and Porpoises				several species present during ice-free period								
AVIFAUNA												
Ducks	important overwintering area			Spring migration		breeding		Fall migration			important overwintering area	
Geese				Spring migration				Fall migration				
Swans				Spring migration				Fall migration				
Seabirds	important overwintering area			Spring migration		breeding		Fall migration			overwintering	
Shorebirds and Cranes												
Raptors												
Upland Game Birds												
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

[1] Arctic Fox

NOME FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ______ MODERATE SENSITIVITY ______ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Polar Bear	minor Winter occurrence											
Brown Bear					sparse occurrence along salmon spawning areas							
Large Carnivores				breeding and whelping arctic foxes								
Moose	sparse occurrence along stream bottoms											
Muskox				Summer concentration area - politically difficult as they are the only significant mainland population								
Caribou and Reindeer	general presence year long - subject to shore based cleanup and habitat degradation											
Aquatic Mammals	in freshwater areas general vulnerability				whelping and rearing			in freshwater areas general vulnerability				
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal				whelping and rearing			general presence					
Bearded Seal	general presence			whelping and rearing							general presence	
Ringed Seal	general presence			whelping and rearing			small summering population				general presence	
Ribbon Seal	along ice edge			whelping and rearing			small summering population				along ice edge	
Walrus Seal				migration and whelping			a few in open water		Fall migration			
Whales and Porpoises					summering and migratory animals							
Fur Seals											transients	
AVIFAUNA												
Ducks				Spring migration	nesting and rearing			Fall migration				
Geese				Spring migration	nesting and rearing			Fall migration				
Swans				Spring migration	nesting and rearing			Fall migration				
Seabirds				Spring migration	nesting and rearing			Fall migration				
Shorebirds and Cranes				Spring migration	nesting and rearing			Fall migration				
Raptors												
Upland Game Birds												
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

CAPE BLOSSOM FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ____ MODERATE SENSITIVITY ____ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Polar Bear	minor occurrence											minor occurrence
Brown and Black Bear						beach - grassland areas						
Large Carnivores												
Moose	wintering concentrations along stream bottoms				calving adjacent to stream areas						wintering concentrations along stream areas	
Caribou		general occurrence			calving and rearing					general occurrence		
Muskox		general occurrence in beach areas			calving and rearing					general occurrence in beach areas		
Aquatic Furbearers		general vulnerability in freshwater areas			breeding and rearing					general vulnerability in freshwater areas		
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal				whelping and rearing				general occurrence marine inshore areas				
Ringed Seal	general occurrence			whelping and rearing					general occurrence			
Ribbon Seal	offshore areas			whelping and rearing				general occurrence but in offshore areas				
Bearded Seal	wintering population			whelping and rearing						wintering population		
Walrus					whelping and migration			a few present in open water		Fall migration		
Fur Seal										transients		
Whales and Porpoises						migrating and summering populations						
AVIFAUNA												
Ducks				Spring migration			breeding and rearing			Fall migration		
Geese				Spring migration			breeding and rearing			Fall migration		
Swans				Spring migration			breeding and rearing			Fall migration		
Seabirds				Spring migration			breeding and rearing			Fall migration		
Shorebirds				Spring migration			breeding and rearing			Fall migration		
Upland Game Birds												
Raptors												
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

PRUDHOE FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ------ MODERATE SENSITIVITY ______ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Polar Bear		general presence				incidental presence					general presence	
Brown Bear					low numbers							
Large Carnivores												
Moose												
Caribou	low occurrence		migration				Summer range			migration	low occurrence	
Aquatic Mammals	general vulnerability in freshwater areas				rearing and whelping		general vulnerability in freshwater areas					
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal				migration, rearing and whelping						migration		
Ringed Seal	....			breeding and whelping			....			....		
Bearded Seal	present in packice		rearing and whelping						present in packice			
Walrus			north migration			whelping and rearing		south migration				
Whales and Porpoises							migrants and Summer feeding					
AVIFAUNA												
Ducks			heavy Spring migration		breeding and rearing			heavy Fall migration				
Geese			heavy Spring migration		breeding and rearing			heavy Fall migration				
Swans			heavy Spring migration		breeding and rearing			heavy Fall migration				
Seabirds			heavy Spring migration		breeding and rearing			heavy Fall migration				
Shorebirds and Cranes			heavy Spring migration		breeding and rearing			heavy Fall migration				
Upland Game Birds												
Other Terrestrial Birds												
Raptors			breeding and rearing snowy owls and peregrine falcons									

SOURCES: A. W. Erickson, personal communication.

UMIAT FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ______ MODERATE SENSITIVITY ______ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Polar Bear												
Brown Bear							concentrated along streams					
Large Carnivores				whelping and rearing								
Moose	Winter concentrations along streams				calving						Winter concentrations along streams	
Caribou			Spring migration calving				summering area					
Muskox			introduced animals spreading - possible impact on this rare animal									
Aquatic Mammals	general vulnerability in freshwater areas				whelping and rearing				general vulnerability			
Other Terrestrial Mammals												
MARINE MAMMALS												
Harbor Seal			Spring migration	whelping and rearing		summering stocks			Fall migration			
Ringed Seal	general presence			whelping and rearing				general presence				
Bearded Seal	present with ice			whelping and rearing							present with ice	
Walrus					Spring migration and whelping and rearing of young			Fall migration				
Whales and Porpoises												
AVIFAUNA												
Ducks			Spring migration			nesting and rearing		Fall migration				
Geese			Spring migration			nesting and rearing		Fall migration				
Seabirds			Spring migration			nesting and rearing		Fall migration				
Shorebirds and Cranes			Spring migration			nesting and rearing		Fall migration				
Upland Game Birds												
Raptors			migration and breeders					migration				
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

YUKON CROSSING FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ______ MODERATE SENSITIVITY ____ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bear							concentrated along salmon streams					
Black Bear												
Large Carnivores												
Moose	concentrated along rivers and on islands				calving and rearing						concentrated along rivers and on islands	
Caribou	possible minor disruption of animals as they interchange through area											
Aquatic Furbearers	general vulnerability				whelping and rearing			general vulnerability				
Other Terrestrial Mammals												
MARINE MAMMALS												
None												
AVIFAUNA												
Ducks			Spring migration		breeding and rearing				Fall migration			
Geese			Spring migration		breeding and rearing				Fall migration			
Swans			Spring migration		breeding and rearing				Fall migration			
Shorebirds			Spring migration			breeding and rearing		Fall migration				
Upland Game Birds												
Raptors				breeding and rearing								
Other Terrestrial Birds												

SOURCE: A. W. Erickson, personal communication.

DENAL‌I FAULT FAUNAL SENSITIVITY PERIODS

...... LOW SENSITIVITY ______ MODERATE SENSITIVITY ______ HIGH SENSITIVITY

FAUNAL GROUP (1)	JANUARY (2)	FEBRUARY (3)	MARCH (4)	APRIL (5)	MAY (6)	JUNE (7)	JULY (8)	AUGUST (9)	SEPTEMBER (10)	OCTOBER (11)	NOVEMBER (12)	DECEMBER (13)
TERRESTRIAL MAMMALS												
Brown Bear						concentrated along stream areas						
Black Bear						concentrated along stream areas						
Moose	wintering along streams				calving						wintering concentrations	
Large Carnivores												
Caribou	wintering animal				calving						wintering concentrations	
Bison	wintering along stream bottoms				calving and rearing						wintering along stream bottoms	
Aquatic Furbearers	general vulnerability in freshwater areas				breeding and rearing			general vulnerability in freshwater areas				
Other Terrestrial Mammals												
MARINE MAMMALS												
None												
AVIFAUNA												
Ducks				Spring migration		nesting and rearing			Fall migration			
Geese				Spring migration		nesting and rearing			Fall migration			
Swans				Spring migration		nesting and rearing			Fall migration			
Shorebirds				Spring migration		nesting and rearing			Fall migration			
Upland Game Birds				Spring migration		nesting and rearing			Fall migration			
Raptors												
Other Terrestrial Birds				Spring migration		nesting and rearing			Fall migration			

SOURCE: A. W. Erickson, personal communication.

APPENDIX D

BIOLOGICAL AND PHYSICAL INFORMATIONAL RESOURCES BY LOCATION

YAKUTAT: INFORMATIONAL RESOURCES

- Yakutat Salmonid Resources
- Fish and Shellfish Important at Yakutat
- Fish and Shellfish Important at Yakutat As Determined From National Marine Fisheries Service Data
- Yakutat Intertidal Species (Personal Communication, Steve Zimmerman to John Isakson, December 26, 1974)
- Resource Assessment of the Gulf of Alaska (National Marine Fisheries Service)
- Yakutat Vicinity Mammals and Birds
- Summary of Surface Weather Observations (Part C - Surface Winds)
- Gulf of Alaska - Surface Winds
- Yakutat - Wind Transition Probabilities

YAKUTAT SALMONID RESOURCES

Sockeye and coho salmon are the most abundant in this area, kings the least abundant. Estimates of abundance are given below (average for period 1960-69):

King	6,000
Sockeye	253,000
Coho	333,000
Pink	50,000
Chums	17,000

There is a set gill net and troll fishery at Yakutat. The timing on the fishery is probably similar to the Bering River District, June-September. The average catches (1960-69) and value are listed below:

	Catch	Value to Fisherman
Kings	2,352	$ 16,048
Sockeye	95,197	187,190
Coho	125,205	257,207
Pink	33,106	17,033
Chum	9,923	11,013

The average catch at Yakutat is approximately 98.8 percent of total Alaska salmon catch with an average value of 1.2 percent of total Alaska.

The run timing extends from June through September. There are local spawning populations of sockeye, pink and coho salmon (kings and chums in very low abundance).

The juveniles move out of freshwater in the late spring and early summer and would be in the coastal area until September. The pink salmon in particular would probably remain in Yakutat Bay until early September before moving into the Gulf of Alaska. They would typically be most abundant in estuarine conditions.

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. State of Alaska. Department of Fish and Game. Statistical Leaflet, 1960 - 1969.

2. International North Pacific Fisheries Commission. Statistical Yearbook, 1960 - 1969.

3. Rosenberg, Donald H. (editor), *A REVIEW OF THE OCEANOGRAPHY AND RENEWABLE RESOURCES OF THE NORTHERN GULF OF ALASKA*, Insititute of Marine Science, University of Alaska, IMS Report R72-23, Sea Grant Report 73-3, February 1972.

FISH AND SHELLFISH IMPORTANT AT YAKUTAT

Halibut
Starry Flounder
Flathead Sole
Butter Sole
Walleye Pollock
Pacific Tomcod
Eulachon (Smelt)
Cottids
Weathervane Scallop
Other Shellfish
Razor Clams

HALIBUT *(Hippoglossus stenolepsis)*[1]

Adults fished commercially offshore from May through September. Area of moderate importance in landings. Spawning occurs in 200 fathoms offshore in this area from December through February. Pelagic eggs and larvae will drift westward with the Alaska Stream.[2]

Juveniles found on open ocean beaches in small quantities from June through October, some inside of Yakutat Bay.[3]

Juveniles feed on small crustaceans and graduate to larger species and fish with increasing size. Adults are primary predators.

A spill in Summer or Fall would have severe short-term effects in displacement of adults and probably mortality of juveniles. Long-term effects would probably be minimal due to drift to larvae from area to the south. If small food items cannot repopulate the area, there may be severe effects from altered food items.

FLATHEAD SOLE[1]

Spawning probably starts as early as April and continues until July in warmer areas of Bering Sea.[4] Feed on Ophiuroids, shrimps, amphipod, fish, and mollusks.[4] Feed on Ophiuroids and crustaceans.[5]

OTHER FLOUNDERS[1]

Species most likely to be affected are shallow water species such as starry flounder *(Platichthys stellatus)*, flathead sole (*Hippoglossoides elassodon)*, and butter sole *(Isopsetta isolepis)*. None are now of commercial importance to the domestic industry but may be in the future. Some are probably taken by foreign trawlers.[6]

Inside of Yakutat Bay starry flounder are probably important.[7] Orcutt reported spawning during December and January in California.[7] Eggs are pelagic and hatch in 4.5 days at 10.5°C. Metamorphoised fish were found on the bottom by March 20th. Feeds on invertibrates, mostly crustaceans, utilizing larger animals with increasing size.[8] Miller also reported on the food habit of adult starry flounder in Washington.[8]

Outside the Bay, the flathead sole is relatively more important. Little is known about life history and feeding habit. It is considered to be a large-mouth flounder and probably feeds on larger organisms, including fish. Under laboratory conditions flathead sole had an incubation time of nine days at 9.6°C and 21 days at 2.4°C.[9] Catches of over 2,000 pounds per hour of flathead sole were reported.[10] This area had best catches of flathead sole in eastern Gulf of Alaska.

SOURCES:

1. Best, E. A., International Pacific Halibut Commission, personal communication.

2. Thompson, W. F., and R. Van Cleve, *LIFE HISTORY OF THE PACIFIC HALIBUT. (2) DISTRIBUTION AND EARLY LIFE HISTORY*, Report of the International Fisheries Commission No. 9, Seattle, 1936.

3. Best, E. A., *JUVENILE HALIBUT IN THE GULF OF ALASKA TRAWL SURVEYS 1970-1972.* Intern. Pac. Halibut Comm. Tech. Rept., 12:63 p., 1974.

4. Mineva, T. A., "On the Biology of Some Flat Fishes in the Eastern Bering Sea," In: *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II.*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

5. Skalkin, V. A., "Diet of Flatfishes in the Southeastern Bering Sea," In: *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART I.*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1963.

6. Schaefers, E. A., and K. A. Smith, *SHELLFISH EXPLORATION IN THE YAKUTAT BAY AREA, ALASKA, BY THE JOHN N. COBB, SPRING 1953.*, Comm. Fish. Rev. 16(3):1-12, 1954.

7. Orcutt, H. G., "The Life History of the Starry Flounder, *Platichthys stillatus (Pallas)*," *CALIF. DEPT. FISH AND GAME, FISH. BULL.*, 78:64 p., 1950.

8. Miller, B. S., "Stomach Contents of Adult Starry Flounder and Sand Sole in East Sound, Washington," *J. FISH. RES. BD. CANADA*, 24(12):2515-2526, 1967.

9. Forrester, C. R., and D. F. Alderdire, "Preliminary Observations on the Embryonic Development of the Flathead Sole (*Hippoglossoides elassodon*)," *FISH. RES. BD. CANADA*, Tech. Rept. 100:20 p., 1968.

10. Hitz, C. R., and W. F. Rathjen, "Bottom Trawling Surveys of the Northeastern Gulf of Alaska (Summer and Fall of 1961 and Spring of 1962)," *COMM. FISH. REV.*, 27(a):1-15, 1965.

FISH AND SHELLFISH IMPORTANT AT YAKUTAT AS DETERMINED FROM NATIONAL MARINE FISHERIES SERVICE DATA

FISH	ABUNDANCE/PRESENCE
Rockfish	Trace at 100 fathoms offshore
Pacific Halibut	Trace near mouth of Yakutat Bay
Other Flatfish	Trace
Sablefish	Trace beyond 100 fathoms

SHELLFISH	
Tanner Crab	Present many locations
King Crab	Absent
Dungeness Crab	Present off east side of Bay mouth
Shrimp	Trace to > 5000 lb/hr in Bay
Scallops	Trace to < 200 lb/hr in Bay

SOURCE: Maturgo, Zenaida A., *EXPLORATORY FISHING DRAGS FOR DEMERSAL FISH AND SHELLFISH, GULF OF ALASKA*, Environmental Conservation Department, Shell Oil Company, Houston - information taken from figures, 1972.

RECEIVED DEC 3 1 1974

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Auke Bay Fisheries Laboratory
P.O. Box 155
Auke Bay, Alaska 99821

December 26, 1974

Mr. John Isakson
Mathematical Sciences Northwest Inc.
P.O. Box 5536
Seattle, Washington 98105

Dear John:

Enclosed are the species lists we discussed. I would like to reiterate the fact that they are incomplete and possibly inaccurate. The incompleteness results from the fact that high surf precluded our working in the lower zones. We probably saw nothing of the species from lower than the middle of the *Mytilus* zone. Inaccuracies, if any, will have resulted because much of the list is based on field work and not laboratory identifications.

In 2 to 3 months we hope to have the Yakutat data back from the sorting center in Fairbanks. At that time we can probably add or correct some species. A good list, however, will not be available until we can work lower in the intertidal zone. Further field work is not scheduled for Yakutat until April.

I hope this may be of some benefit to you.

Sincerely,

Steven T. Zimmerman

Steven T. Zimmerman
Oceanographer

Enclosure

Green algae

1 Enteromorpha sp. (juv)
1 Spongomorpha saxatalis (s) on Rhodymenia palmata
1 Ulva (rigida) (juv) on Rhodymenia palmata

Brown algae

1 Fucus distichus (f)
2 Petalonia fascia on Rhodymenia palmata
1 Pilayella littoralis (unilocular) on wood

Red algae

1 Callithamnion pikeanum var. pacificum (♀, ♂?, ⊕)
1 Endocladia muricata
1 Gigartina exasperata
2 Gigartina papillata
3 Odonthalia floccosa
1 Polysiphonia hendryi (θ)
4 Porphyra sp. (f)
1 Rhodymenia palmata

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Auke Bay Fisheries Laboratory
P. O. Box 155, Auke Bay, Alaska 99821

Date : 23 December, 1974 Reply to Attn. of:

To : S. Zimmerman

From : N. Smith

Subject: Yakutat intertidal species

Following is a list of Yakutat intertidal species taken from my field notes. It is incomplete and probably inaccurate. They have not been confirmed by lab identification.

Coelenterata
- Anthopleura sp.
- small brown anemone
- hydroids

Porifera
- orange encrusting sponge

Nemertinea
- green nemertean
- white nemertean

Echinodermata
- Leptasterias sp.

Annelida
- Eudistylia sp.

Mollusca
- Katharina tunicata
- Acmaea persona
- A. digitalis
- A. fenestrata
- Littorina sitkana
- Thais sp.
- Mytilus edilus

Crustacea
- Balanus cariosus
- Balanus glandula
- Pagurus hirsutiusculus
- Cancer magister

RESOURCE ASSESSMENT OF THE GULF OF ALASKA

Prepared by

National Marine Fisheries Service
Northwest Fisheries Center
Seattle, Washington

December 1974

GULF OF ALASKA

Fish and Invertebrate Resources

The Gulf of Alaska is inhabited by many diverse forms of fishes and invertebrates. Occurrences and relative abundance of some species are well defined while data on other species are almost non-existent. The following comments, therefore, are based on the existing state of knowledge and will be accurate for some species and may entirely overlook others. These comments are for the proposed lease areas from Yakutat Bay to Cape Cleare, including the eastern portion of Prince William Sound.

The fish fauna of the Gulf of Alaska can be subdivided into two groups, the pelagic species and the demersal species. Pelagic species which are either presently considered commercially important or are potentially of commercial importance include five species of salmon (family Salmonidae), four species of smelt (Osmeridae) and one species of herring (Clupidae) and one species of pomfret (Bramidae). In the proposed lease areas, the most abundant species of pelagic fish include the pink salmon (Oncorhynchus gorbuscha), chum salmon (O. keta), sockeye salmon (O. nerka), Pacific herring (Clupea harengus pallasi), Pacific pomfret (Brama japonica), eulachon (Thaleichthys pacificus), and capelin (Mallotus villosus).

The demersal fish community can be further subdivided into elasmobranchs, flatfish, roundfish, and rockfish. Of the five species of elasmobranchs found in the eastern Gulf of Alaska, the most abundant species in the lease area are the big skate (Raja binoculata) and longnose skate (R. rhina). The flatfish group is the largest species complex in the Gulf of Alaska and includes approximately 15 species. In the proposed lease area the most abundant species include halibut (Hippoglossus stenolepis), turbot (Atheresthes stomias), flathead sole (Hippoglossoides elassodon), rex sole (Glyptocephalus zachirus), Dover sole (Microstomus pacificus), butter sole (Isopsetta isolepis), and starry flounder (Platichthys stellatus). Principal roundfish species include Pacific cod (Gadus macrocephalus), pollock (Theragra chalcogramma), and sablefish (Anoplopoma fimbria). One group of roundfish, the rattails (Coryphaenoides), occurs in deeper water than most of the other demersal species. We know little about the distribution, abundance, and life history of rattails, which are being increasingly exploited by the USSR in the Gulf of Alaska and Bering Sea. The rockfish group is dominated by Pacific ocean perch (Sebastes alutus).

The invertebrate populations presently of commercial importance include the king crab (Paralithodes camtshatica), golden king crab (Lithodes aequispina), Snow crab (Chionoecetes bairdi), Dungeness crab (Cancer magister), razor clam (Siliqua patula), weathervane scallop (Patinopecten caurinus), and pandalid shrimp (Pandalidae).

Species which are potentially of commercial importance are almost too numerous to mention. Those which occur in the proposed lease site and which are utilized in other areas of the world include snails, mussels, clams, sea urchins, sea cucumbers, seaweed, kelp, and shrimp other than pandalids; however, little data are available on many of these species.

Several commercial fisheries, foreign and domestic, occur in and around the proposed lease area. Otter trawl fisheries by Japan and the Soviet Union harvest large quantities of Pacific ocean perch, flatfish, and other demersal fishes. Longline fisheries are conducted for sablefish by the Japanese and for sablefish and halibut by the United States and for halibut by the Canadians. Salmon fisheries are conducted by U.S. nationals by trolling in continental shelf waters and by purse seining and gillnetting inside Prince William Sound and off the mouth of the Copper River. Pot fisheries by U.S. nationals for Snow crab, king crab, Dungeness crab, and spot shrimp occur inside Prince William Sound and offshore for Snow and Dungeness crabs. Limited dragging for pandalid shrimp has occurred in past years. A dredge fishery for scallops is pursued by U.S. fishermen on the continental shelf. while razor clams are harvested by digging on the Cordova Flats.

Catch statistics for these fisheries are not readily available explicitly for the proposed lease area. Readily available catch statistics for U.S. landings for the time period 1967-1971 include both the eastern and western Gulf of Alaska (Table 1); Japanese and Russian catch statistics for the same area are from 1967-1973 (Tables 2 and 3).

From 1967 to 1971 fish catches in the Gulf of Alaska for the United States, Canada, Japan, and the Soviet Union ranged from 232,322 to 258,148 metric tons and averaged 243,834 metric tons.

A notable change in recent years has been a reduction in the rockfish catch. In the peak years of 1964 and 1965 the Russians and Japanese harvested 240,739 and 375,027 metric tons of rockfish, mostly Pacific ocean perch, from the Gulf of Alaska. Catches of rockfish from 1967-1973, by the USSR and Japan, ranged from 50,029 to 120,194 and averaged only 80,132 metric tons per year, reflecting the earlier heavy exploitation of this resource.

The many fishes and invertebrates which inhabit the proposed lease area and adjacent waters are renewable resources. As such, they are capable of providing large yields of food, sources of employment, and recreation to perpetuity if protected from environmental degradations and if managed properly. Opportunities for effective management of the fisheries would be vastly increased if the U.S. had jurisdiction over the resources and could control the fishing activities of foreign as well as domestic fishermen. This control appears to be soon forthcoming and will likely include all waters within 200 miles of the

U.S. coast with additional seaward controls for the far-ranging salmons An important by-product of extended fisheries jurisdiction will be improved access to the resources by U.S. fishermen. Consequently, the already large value of the fisheries resources to the U.S. will soon be vastly increased when extended jurisdiction occurs.

Migrations within or through the proposed lease area are poorly understood for most fish species. King and silver salmon feed during th late spring and summer months in the offshore waters from the Fairweathe grounds to Middleton Island. During the summer months most species of salmon migrate through the proposed lease area returning to their spawning streams. Although groundfish and invertebrate migrations are not well documented for the lease area, general knowledge is available. Most groundfish species move to deeper water during winter months and back to shallower water in summer. Both Snow and king crab spend the summer in deeper water and migrate to shallow water during the winter to spawn.

Tagging studies have shown that sablefish migrate extensively throughout the North Pacific, including between Asia and North America. We do not know the exact time or routes of these migrations, but it is noteworthy that a juvenile sablefish which was tagged and released in Puget Sound was subsequently recovered near Middleton Island.

Oil exploration will undoubtedly cause conflicts with existing and potential fisheries in the lease area. Establishment of drilling platforms and their anchoring systems will physically take up space and interfere to some extent with most fisheries. Establishment of drilling platforms will increase the vessel traffic in the lease area, thereby increasing navigation and fishing hazards. If pipelines are used to move oil to storage or loading facilities, they will compete for physical space and can restrict some forms of commercial fishing unless they are buried beneath the sea floor.

Drilling platforms and pipelines may cause considerable loss and damage to fishing gear if located in high fish density areas. Otter trawls which are towed on or near the sea floor by fishing vessels would be particularly susceptible to damage as would longlines which are often laid out over several miles on the sea floor. Knowledge of the types and locations of drilling platforms and pipelines to be used would be required before more definitive statements could be made about their potential impact on the fisheries. Increased human useage of the area will undoubtedly increase pollution unless the operations are closely monitored.

Major disasters, such as oil spills, pipeline breaks, etc., could be extremely detrimental to the fishery resources. Sedentary animal populations could sustain large mortalities; however, mobile animals would be less susceptible to harm if they are able to move to uncontaminated waters.

Because of the westward water flow, Alaska Current, along the shelf edge at the head of the Gulf of Alaska, oil spills which occur also threaten the animal populations located westward and shoreward of a disaster site.

Marine Mammal Resources

The marine mammals known to live in the Gulf of Alaska at least a portion of each year are listed in the accompanying Table 4, and estimates of the numbers of animals are given for each species, if possible. Source of data is also listed.

Harbor seals and northern sea lions are found primarily in shallow coastal waters although sea lions may occasionally be found on the offshore fishing banks. These two species are present throughout the year.

Northern fur seals are probably found in the offshore areas of the Gulf in small numbers during most months of the year with population peaks occurring in November-December and in April-May-June, when they are migrating southward in winter and northward in spring. As many as half the Pribilof population may be in the Gulf during spring migration.

Certainly at least 75% of the gray whale population passes through the Gulf twice each year during migration to and from the Chukchi Sea summer grounds and the Baja California calving lagoons. During at least part of their migration they are found in coastal waters.

The sei, fin, blue, humpback, and sperm whales generally move in and out of the offshore areas seasonally as do some of the other whales, porpoises, and dolphins. The humpback enters coastal waters more frequently than the other species.

The right whale, harbor porpoise, and Dall porpoise may be resident year round, as is the sea otter. The harbor porpoise and sea otter inhabit coastal waters. The right whale and Dall porpoise may enter coastal waters infrequently.

Effect of seepage and spills in the Gulf of Alaska

Harbor seals and sea lions will probably be most vulnerable to direct oil pollution during birth of pups and for the first few weeks of the pups lives on the rookery areas.

Fur seals may occasionally encounter oil spills during migration. The dense underfur of the seal acts as insulation and matting of this fur by oil products may break the insulating barrier and cause death from exposure. Major spills along the continental shelf in the Gulf, particularly in the spring, could result in the death of substantial numbers of fur seals.

The effect of oil on cetaceans is unknown. Kenyon (1971) quotes W. Von Utrecht, who states: "Small cetacea are now rare in the southern North Sea, whose heavy ship traffic, oil and gas exploration and industrial contamination might all be contributory factors to either avoidance or death."

Sea otters are particularly susceptable to oil pollution; once its fur mats and water reaches its skin (the animal has no blubber layer), the animal suffers heat loss and soon dies of exposure. Kenyon (1971) reports the death of two sea otters in a holding pool after oil accidentally entered the pool water supply. A leak or spill contaminating any sea otter area would almost certainly result in the death of all sea otters encountering the oil.

Because of the uncertainties as to the location and type of drilling platforms and pipelines, fate of oil spilled in any particular area, and biological reactions of most organisms when exposed to oil, we are presently unable to evaluate the potential impact of the accelerated program of offshore leasing on the fish, invertebrate, or mammal resources.

Table 1.--Catch statistics for United States landings from the Gulf of Alaska 1967-1971 in metric tons.

Species	1967 Catch	1967 Value	1968 Catch	1968 Value	1969 Catch	1969 Value	1970 Catch	1970 Value	1971 Catch	1971 Value	1972 Catch	1972 Value	1973 Catch	1973 Va
Herring	2,348	78	1,958	43	2,572	113	4,682	206	1,875	158				
Herring eggs on kelp	10	16	25	68	2	8	86	95	349	385				
Sablefish	44	9	0	0	1	[illegible]	5	2	10	3				
King crab	37,654	9,593	17,037	10,517	9,197	5,677	8,885	5,378	9,172	5,902				
Dungeness crab	3,417	979	4,196	1,295	3,779	1,183	3,037	993	936	335				
Tanner crab	53	12	1,408	310	4,483	1,008	5,636	1,222	5,653	1,327				
Shrimp	17,694	1,560	18,132	1,735	20,943	1,847	33,248	2,932	42,607	3,814				
Razor clams (meats)	27	30	15	20	18	13	30	40	46	70				
Scallops	-	1	357	613	477	839	643	1,460	384	905				
Salmon														
King	249	139	211	149	320	236	416	299	482	390				
Chum	4,362	832	10,439	2,532	5,668	1,455	11,204	2,765	13,282	3,907				
Pink	6,662	1,552	25,403	6,720	38,246	12,161	32,592	9,633	23,452	8,270				
Sockeye	8,519	4,715	11,716	6,715	10,596	5,934	16,987	9,756	10,794	6,053				
Coho	1,819	649	2,955	1,564	881	389	2,351	1.319	1,820	845				
Halibut *	42,582		36,749		26,514		19,933		19,588		16,155		14,318	
Groundfish	30		59		51		45		760		0		70	
TOTAL	125,470		130,660		123,748		139,778		131,210		**		**	

* Halibut catch dressed weight.

**All catch statistics not available for 1972 and 1973.

Table 2.--Soviet cat[illegible] statistics from the Gulf of Al[illegible]a 1967-1973 in metric tons.

Year	Pollock	Rockfish	Cod	Halibut	Flatfish	Others	Sablefish	Total
1967		66,485				10,452		76,937
1968		45,186				14,236		59,422
1969		18,823				1,191		20,014
1970		7,282				2,054		9,336
1971	440	29,700	176			403		30,719
1972	20,385	24,011	2,696	302	1,363	19,572	535	68,864
1973	15,813	4,341	2,824	162	939	15,678	109	39,866

Source: U.S.S.R. Catch Statistics

Table 3.--Japanese catch statistics for the Gulf of Alaska 1967-1973 in metric tons.

Year	Sablefish	Cod	Pollock	Pacific Ocean Perch	Other Rockfish	Other Fish	Total
1967				53,709			53,709
1968	13,866			54,200			68,066
1969	19,5[illegible]	199	13,675	55,503	1,672	4,003	95,640
1970	21,3[illegible]7	1,765	11,470	44,291	608	4,539	84,070
1971	25,636			44,757			70,393
1972	34,259	719	13,909	51,284	1,785	7,957	109,914
1973	29,249	2,469	7,337	49,896	7,392	21,112	117,455

Source: INPFC Catch Statistics

Table 4.--The marine mammals found along the shores or in the Gulf of Alaska are:

SPECIES		REMARKS
<u>Pinnipedia</u>		
Harbor Seal	<u>Phoca vitulina</u>	local resident -- pop. est. 110,000[1/]
Elephant Seal	<u>Mirounga angustirostris</u>	rare straggler
Northern (Steller) Sea Lion	<u>Eumetopias jubatus</u>	local resident -- pop. est. 46,800[1/]
Northern Fur Seal	<u>Callorhinus ursinus</u>	abundant in migration -- pop. est. 650,000[2/]
Walrus	<u>Odobenus rosmarus</u>	rare straggler
<u>Cetacea</u>		
Large Whales		
Right Whale	<u>Balaena glacialis</u>	protected, rare -- pop. est. 50[3/]
Gray Whale	<u>Eschrichtius gibbosus</u>	protected, abundant in migration pop. est. 8,250[5/]
Minke Whale	<u>Balaenoptera acutorostrata</u>	common -- pop. est. 200[3/]
Sei Whale	<u>Balaenoptera borealis</u>	common -- pop. est. 300[3/]
Fin Whale	<u>Balaenoptera physalus</u>	protected, common -- pop. est. 1,000[3/]
Blue Whale	<u>Balaenoptera musculus</u>	protected, few -- pop. est. 120[3/]
Humpback Whale	<u>Megaptera novaeangliae</u>	protected, few, locally common pop. est. 20[3/]

Table 4.--The marine mammals fou..u along the shores or in the Gulf of Alaska, continued

SPECIES		REMARKS
Cetacea		
Large Whales (continued)		
Sperm Whale	Physeter catodon	common -- pop. est. 600[3]
North Pacific Giant Bottlenose Whale	Berardius bairdi	numbers unknown
Small Whales, Dolphins, Porpoises		
Risso's Dolphin	Grampus griseus	may stray north into Gulf
White-sided Dolphin	Lagenorhynchus obliquidens	seen in summer -- 2000+ in one pod 21 May 1968[4]
Northern Right Whale Dolphin	Lissodelphis borealis	may stray north into Gulf
False Killer Whale	Pseudorca crassidens	numbers unknown
Short-finned Pilot Whale	Globicephala macrorhyncha	one record
Killer Whale	Orcinus orca	common -- pop. est. 100[3]
Harbor Porpoise	Phocoena phocoena	common coastal -- pop. est. 1,000[3]
Dall Porpoise	Phocoenoides dalli	common - most abundant -- pop. est. 2,000[3]
Beluga	Delphinapterus leucas	300 - 500 Cook Inlet[1]
Bering Sea Beaked Whale	Mesoplodon stejnegeri	several records, numbers unknown
Goose-beaked Whale	Ziphius cavirostris	several records, numbers unknown

Table 4.--The marine mammals found along the shores or in the Gulf of Alaska, continued:

SPECIES		REMARKS
Mustelidae		
Sea Otter	Enhydra lutris	locally abundant coastal -- pop. est. 10,500[1/]

Data Source for Population Estimates:

1/ Alaska Department of Fish and Game, Marine Mammal Status Reports, 1973.

2/ NMFS, NWFC, MMD, 1974 data Pribilof Fur Seal Populations 1.3 million, estimate 50% pass through Gulf of Alaska.

3/ Scheffer, V. B., Chapter 10, Marine Mammals in the Gulf of Alaska, In A review of the oceanography and renewable resources of the northern Gulf of Alaska. D.H. Rosenburg (editor). Institute of Marine Science, University of Alaska, Fairbanks.

4/ NMFS, NWFC, MMD, 1968. Records of mammals observed at sea.

5/ Report of Secretary of Commerce. Adm. of Marine Mammal Protection Act. Fed. Register 39(122) p. 23914, Gray Whale pop. 11,000 -- estimate 75% pass through Gulf of Alaska.

References

Alverson, D.L.
1960. A study of annual and seasonal bathymetric catch patterns for commercially important groundfishes of the Pacific Northwest coast of North America. Bull. Pacific Marine Fish. Comm. 4: 66 p.

Alverson, D.L., A.T. Pruter, and L.L. Ronholt.
1964. A study of demersal fishes and fisheries of the northeastern Pacific Ocean. H.R. MacMillan Lectures in Fisheries, Univ. British Columbia, Inst. Fish. 190 p.

Alverson, D.L. and W.T. Pereyra
1969. Demersal fish explorations in the northeastern Pacific Ocean - an evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. Journ. Fish. Res. Bd. Canada, Vol. 26, No. 8.

Hitz, C.R. and W.F. Rathjen.
1965. Bottom trawling survey of the northeastern Gulf of Alaska (summer and fall of 1961 and spring of 1962). Comm. Fish. Rev. 27(9): 1-15.

Kenyon, K.W.
1971. The effect of oil pollution on marine mammals. Dept. of Inter. 102 Statement Task Force B of the Task Force on Alaska Oil Development. 9 p. processed.

Low, L.L.
1974. Atlas of Japanese fisheries in the northeast Pacific, January 1970 to October 1972: Three-dimensional graphs of monthly catch statistics. National Marine Fisheries Service, Northwest Fisheries Center, Processed Report No. 2.

Ronholt, L.L.
1963. Distribution and relative abundance of commercially important pandalid shrimps in the northeastern Pacific Ocean. U.S. Fish Wildlife Serv. SSR-F 449, 28 p.

Schaefers, E.A. and K.A. Smith
1954. Shellfish explorations in the Yakutat Bay area, Alaska, by the John N. Cobb, spring 1953. U.S. Fish Wildlife Serv., Comm. Fish. Rev., Vol. 16, No. 3, p. 1-12.

Schaefers, E.A., K.A. Smith, and M.R. Greenwood
1955. Bottomfish and shellfish explorations in the Prince William Sound area, Alaska 1954. Comm. Fish. Rev. 17(4): 6-28.

YAKUTAT VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1]	Beaches Grass Flats	No precise estimate, 15 to 20 taken by hunters annually.
Black Bear[1, 2]	Beaches Grass Flats	No population estimate. Most significant concern is the rare glacier color phase, which may be given endangered species status in the future.
Goats[2]		
Wolves and Wolverines[1]	Grass Flats Forest Edge	Relatively few wolves and wolverines in Unit 5. Denning near grass flats.
Moose[1]	Willow Flats	Estimated population of 4,000 to 5,000; Annual kill 30. Highest productivity of any American moose herd.
Blacktail Deer[1]	Beaches Forest Edge	Mainly on islands, few on mainland; annual kill about 100. Poor Summer range on islands.
Harbor Seal[1]	Beaches Mud Flats	Very abundant in unit. Annual recent harvest of 4,000 to 6,000. Currently protected by Marine Mammal Protection Act.
Northern Fur Seal[1]		Migrant animals.
Sea Lion[1]	Rocky Coves Beaches	Present throughout unit - population of 1,000 at Sitkage Bluffs just off Yakutat Bay to the west.
Sea Otter[1]	Inshore Seas Caves	Total numbers unknown. Reintroduced in 1966. Have been observed throughout Unit 5 waters. Population low but believed to be increasing.
Aquatic Furbearers[2]	Estuaries Marshes	Beaver, otter, mink, muskrat. Impact on food plants and organisms, possible den mortality of young in Spring.
Whales and Porpoises[1]	Open Sea	Dall and harbor porpoises in coast waters. Humpback and fan whales in outer waters. Gray whale migration zone.
Ducks[1]	Open Sea Marshes Estuaries	Major migration area - particularly intertidal and along shore. Untold thousands of Fall and Spring ducks. Overwintering mallards, some divers and sea ducks.
Geese[1]	Nearshore Seas Beaches Mud Flats Estuaries	Heavy Fall and Spring migrations, 1,000 snow geese, 10,000 Canada geese. Breeding population of Canadas believed to be Vancouver Race. Large overwintering population of Canada geese.

YAKUTAT VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Swans[1]	Near Shore Seas Beaches Estuaries Mud Flats	Fall migrations of both species 3,000. Small overwintering population believed to be trumpeters.
Seabirds[1]	Near Shore Seas Beaches Estuaries	Many colonies throughout area. Species predominantly glaucous winged gulls, pigeon guillemot, black-legged kittiwake.
Shorebirds[2]	Beaches Mud Flats	Possible impact on food organisms, damage to nesters during Spring.
Upland Game Birds[2]		
Raptors[2]		

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

CLIMATOLOGICAL DATA FOR YAKUTAT

YAKUTAT, ALASKA (Federal Aviation Agency Airport), 59°31'N., 139°40'W.; Elevation (ground) 28 feet. WB-1961

Month	Air temperature (°F.)					Precipitation (inches)			Humidity (percent)		Wind (knots)			Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days						
	Normal			Extreme												Sunrise to sunset						
	Daily maximum	Daily minimum	Monthly	Record highest	Record lowest	Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	9:00 a.m. Local time	3:00 p.m. Local time	Mean speed	Prevailing direction	Maximum speed and direction			Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				15	15		15	13	13	13	13	13			13	13	13	13	15	13	13	13
Jan.	33.0	19.9	26.5	49	-22	11.60	5.10	38.1	82	80	7.6	E			7.5	6	4	21	18	8	*	2
Feb.	34.9	21.1	28.0	49	-19	8.61	2.35	44.1	85	79	7.8	E			8.0	4	3	21	17	11	0	2
Mar.	36.0	23.5	30.8	55	-13	9.89	3.33	43.7	82	73	7.1	E			7.7	4	5	22	17	9	0	3
Apr.	44.4	28.6	36.5	66	3	7.93	2.69	16.7	79	72	6.9	E			8.0	4	5	21	17	5	0	2
May	51.2	35.3	43.3	76	22	7.52	3.50	0.5	79	74	7.2	ESE			8.3	3	5	23	18	*	0	3
June	56.8	42.2	49.5	81	30	4.96	2.50	0.0	81	75	7.0	ESE			8.5	2	5	23	15	0	0	4
July	58.6	46.8	52.7	84	36	8.63	5.36	0.0	84	79	6.3	ESE			8.6	2	5	24	17	0	*	3
Aug.	59.3	46.2	52.8	86	30	10.54	4.77	0.0	86	79	6.3	ESE			8.5	3	4	24	18	0	*	5
Sep.	55.0	41.8	48.4	77	25	16.22	6.38	T	88	79	6.6	E			8.6	2	4	24	20	0	*	4
Oct.	47.9	35.4	41.7	60	12	19.93	4.24	4.9	86	77	7.7	E			8.4	4	2	25	23	1	*	1
Nov.	39.6	27.8	33.7	59	-10	15.46	7.13	20.4	88	84	8.2	E			8.5	3	3	24	21	4	*	1
Dec.	33.7	21.8	27.8	52	-15	12.31	3.76	47.6	87	86	8.6	E			8.6	3	3	25	23	11	*	2
Year	46.0	32.5	39.3	86	-22	134.15	7.13	216.0	84	78	7.3	E			8.3	40	48	277	224	50	1	31

SOURCE: U. S. Department of Commerce and Coastal and Geodetic survey, *PACIFIC AND ARCTIC COASTS - ALASKA, CAPE SPENCER TO BEAUFORT SEA*, Seventh Edition (October 3, 1974), U. S. Coast Pilot Volume 9.

DATA PROCESSING DIVISION
ETAC/USAF
AIR WEATHER SERVICE/MAC

PERCENTAGE FREQUENCY OF WIND
DIRECTION AND SPEED
(FROM HOURLY OBSERVATIONS)

SURFACE WINDS

25339 (STATION) YAKUTAT ALASKA/STATE APT (STATION NAME) 41-71 (YEARS) ALL (MONTH)

ALL WEATHER (CLASS) ALL (HOURS (L.S.T.))

(CONDITION)

SPEED (KNTS) DIR	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥56	%	MEAN WIND SPEED
N	.2	.5	.2	.0	.0	.0						1.3	4.7
NNE	.4	.5	.2	.0	.0	.0						1.1	4.7
NE	1.1	1.4	.8	.2	.1	.0	.0	.0				3.6	5.8
ENE	1.4	3.9	3.4	1.3	.3	.1	.0	.0	.0	.0		10.3	7.3
E	2.7	5.3	7.2	3.9	.9	.3	.1	.0	.0			20.5	8.5
ESE	1.1	2.7	4.6	4.2	1.4	.6	.2	.1	.0	.0	.0	15.0	11.1
SE	.5	1.1	1.7	1.6	.6	.5	.2	.1	.0	.0		6.3	12.1
SSE	.2	.5	1.0	.8	.3	.2	.1	.0	.0			3.1	10.8
S	.3	.5	.3	.4	.1	.0	.0	.0				2.3	8.6
SSW	.2	.5	.5	.3	.1	.0	.0	.0	.0	.0		1.6	8.2
SW	.5	.7	.8	.3	.1	.0	.0	.0	.0			2.3	7.6
WSW	.4	1.0	1.4	.6	.1	.0	.0	.0	.0			3.5	8.0
W	.7	1.0	1.2	.4	.0	.0	.0					3.4	6.9
WNW	.5	1.1	1.0	.2	.0	.0						2.9	6.2
NW	.7	1.1	.9	.1	.0	.0						2.8	5.8
NNW	.4	.6	.5	.1								1.5	5.6
VARBL													
CALM												18.3	
	11.7	22.5	26.3	14.4	4.0	1.9	.6	.2	.0	.0	.0	100.0	7.0

TOTAL NUMBER OF OBSERVATIONS 224017

SOURCE: National Climatic Center, "UNIFORM SUMMARY OF SURFACE WEATHER OBSERVATIONS (SSWO)", Revised, Part C - Surface Winds.

USAFETAC FORM AA 64 0-8-5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

GULF OF ALASKA I - SURFACE WINDS

Station	Winter		Summer		Fastest Mile		2nd Fastest Mile	
	Prevailing Direction	Mean Speed (mph)	Prevailing Direction	Mean Speed (mph)	Direction	Speed (mph)	Direction	Speed (mph)
Cape Spencer	NE		NE; W					
Yakutat	E	8	E; SE	7	SE	75	SE	63
Yakataga	SE	7.5	SE	6.5				
Cape St. Elias	SE		SE					
Katalla								
Cordova	E; SE	5	E; SE; SW	4.5				
Cape Hinchinbrook								
Valdez	NE; E	13.5	SW	9	N; NE; E	46		
Whittier	SW; NE		NE; SW					
La Touche	N		N					
Seward	N		S		N	64		
Middleton Island	E; SE	17	SW; SE	12	NE*	78	SE	76

*Maximum estimated gust of 109 mph occurred on January 26, 1953.

SOURCE: Swift, W. H., R. E. Brown, L. V. Kinnel, M. M. Orgel, P. L. Petersen, W. W. Waddell, *GEOGRAPHICAL ANALYSIS OF OIL SPILL POTENTIAL ASSOCIATED WITH ALASKAN OIL PRODUCTION AND TRANSPORTATION SYSTEMS*, Pacific Northwest Laboratory, Division of Memorial Institute to the United States Coast Guard, February 1974, Final Report No. CG-D-79-74.

WIND TRANSITION PROBABILITIES

3 HOUR TRANSITION MATRIX: WINTER   YAKUTAT, ALASKA

	CALM	N	NE	E	SE	S	SW	W	NW
CALM	0.691	0.030	0.112	0.111	0.023	0.006	0.003	0.011	0.014
N	0.343	0.043	0.100	0.229	0.043	0.057	0.014	0.057	0.114
NE	0.185	0.029	0.327	0.398	0.031	0.010	0.003	0.009	0.007
E	0.073	0.007	0.154	0.659	0.077	0.011	0.009	0.006	0.003
SE	0.057	0.007	0.084	0.324	0.395	0.091	0.020	0.014	0.007
S	0.041	0.017	0.091	0.198	0.140	0.380	0.091	0.025	0.017
SW	0.094	0.047	0.156	0.109	0.047	0.172	0.281	0.078	0.016
W	0.250	0.038	0.077	0.058	0.077	0.038	0.192	0.212	0.058
NW	0.439	0.073	0.073	0.171	0.049	0.073	0.000	0.024	0.098

WIND STATISTICS FOR WINTER

DIRECTION	MEAN	STD DEV
CALM	0.0000E+00	0.0000E+00
N	4.0428E+00	1.5347E+00
NE	6.3711E+00	3.6488E+00
E	8.6851E+00	4.4299E+00
SE	1.1811E+01	7.1261E+00
S	9.2810E+00	4.0782E+00
SW	9.5938E+00	3.7405E+00
W	6.9231E+00	4.5777E+00
NW	4.6829E+00	2.2679E+00

SOURCE: Massachusetts Institute of Technology, *PRIMARY, PHYSICAL IMPACTS OF OFFSHORE PETROLEUM DEVELOPMENTS*, report to the council on Environmental Quality, MITSG 74-20, April 1974.

VALDEZ HARBOR AND NARROWS: INFORMATIONAL RESOURCES

- Valdez Harbor and Valdez Narrows Salmonid Resources
- Fish and Shellfish Important at Valdez
- Fish and Shellfish Important at Valdez Harbor/Narrows Determined from National Marine Fisheries Service Data
- Flora and Fauna of Valdez Harbor and Narrows
- Biological Resources of Valdez Harbor/Narrows
- Valdez Vicinity Mammals and Birds
- Climatological Data for Prince William Sound Region (Cordova)
- Wind Speed at Jackson Point and Valdez Airport
- Cordova Surface Wind Data

VALDEZ HARBOR AND VALDEZ NARROWS SALMONID RESOURCES

There is a large commercial salmon fishery in Prince William Sound with an average total value of over $2 million to the fisherman. Pink salmon are the most important, followed by sockeye and chum salmon. The average runs and values (1960-1969) are listed below:

	RUN	VALUE TO FISHERMAN	CATCH	PERCENT OF TOTAL ALASKA CATCH
Kings	4,000	$ 9,667	1,642	2.8
Sockeye	254,000	140,448	95,420	6.5
Coho	76,000	36,449	28,750	19.6
Pink	5,318,000	1,571,712	3,545,168	12.2
Chum	796,000	301,626	454,591	8.7

The abundance of salmon in the immediate area of the spill sites is difficult to determine. The harbor environment is probably most important to pink and chum salmon juveniles using the estuarine conditions for early feeding and growth. They could be in the area from May through September. The run and fishery timing for Prince William Sound is June through September. There are some major spawning sites in Valdez from which could be important for both spill sites as some of the spawning is intertidal. Average abundance (1962-1970) are listed below:

	NO SPAWNERS	PERCENT INTERTIDAL
Pinks	180,770	77
Chums	46,500	73

There are both subsistance and sport catches of salmon in the Valdez area but they are of little importance compared to the commercial catch.

NOTE: Here are some commercial catch statistics for the ADF Statistical Area (221) that includes Valdez Harbor, Narrows and vicinity. (Average catch 1965-1971 in thousands)

Sockeye	1.0	(0.3-2.5)
Pink	840.2	(358.7-1,974.8)
Chum	128.7	(27.3-200.4)
Coho	6.9	(1.8-18.0)
King	0.09	(0.02-0.4)

VALDEZ HARBOR AND VALDEZ NARROWS SALMONID RESOURCES (CONT'D.)

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. State of Alaska, Department of Fish and Game. Statistical Leaflet. Published annually.

2. International North Pacific Fisheries Commission. Statistical Yearbook.

3. Rosenberg, Donald H. (editor), *A REVIEW OF THE OCEANOGRAPHY AND RENEWABLE RESOURCES OF THE NORTHERN GULF OF ALASKA*, Institute of Marine Science, University of Alaska, IMS Report R72-73, Sea Grant Report 73-3, February 1972.

FISH AND SHELLFISH IMPORTANT AT VALDEZ [1]

Walleye Pollock
Pacific Cod
Black Cod
Rockfish
Halibut
Herring
Rex Sole
Arrowtooth Flounder
Tanner Crab

The report on the Valdez area covers salmon in detail and states that the five species are the most important economically, and recreationally, of all species of fish.

Schaefers, Smith & Greenwood[2] reported a limited number of tows in Valdez Arm. Catches included pollock, Pacific cod, black cod and red rockfish, as well as halibut, rex sole, and turbot during March. A second survey in July added English sole, flathead sole, and Pacific Ocean perch to the list.

See Yakatut for information on most of these species.

There should be more information available on herring and shellfish fisheries of the area. Landing statistics for Prince William Sound report substantial landings of tanner crab from November through July.

HALIBUT

Relatively unimportant commercially in the immediate vicinity of Valdez. May support some recreational fishery and part time commercial effort. The offshore area around Cape St. Elias is more important to the commercial fleet. The inclusive areas around Cape St. Elias are of increased importance to the juvenile halibut during the Summer and Fall.[3] Eggs and larvae from spawning areas in the Gulf of Alaska drift inshore and settle in the shallows beginning in May.

ROCKFISH

The Valdez report states there is some recreational fishing for rockfish although little information is available. The yellowtail rockfish *(Sebastes flavidus)*, was shown to have very strong homing instinct and return to the home area after having displaced 5 to 7 miles.[4] Rockfish are known to be ovoviparous, fertilization is internal and the larvae are spawned. Homing instinct and spawning habits indicate that the long-term effect might be relatively greater.

SOURCES:

1. Best, E. A., International Pacific Halibut Commission

2. Schaefers, E. A., K. A. Smith, and M. R. Greenwood, "Bottom Fish and Shellfish Explorations in the Prince William Sound Area, Alaska, 1954," *COMM. FISH. REV.*, 17(4):6-28, 1955.

3. Best, E. A., "Juvenile Halibut in the Gulf of Alaska Trawl Surveys, 1970-1972," *INTERN. PACIFIC HALIBUT COMM. TECH. REPT. 12*, 63 pp., 1974.

4. Anonymous, "Rockfish Show a Strong Homing Instinct," *COMM. FISH. REV.*, 32(8-9):7, 1970.

FISH AND SHELLFISH IMPORTANT AT VALDEZ HARBOR/NARROWS DETERMINED FROM NATIONAL MARINE FISHERIES SERVICE DATA

	ABUNDANCE/PRESENCE
FISH	
Rockfish	Trace - more in outer Prince William Sound
Pacific Halibut	Traces all over Prince William Sound
Other Flatfish	Traces in Eastern Prince William Sound
Sablefish	Trace
SHELLFISH	
Tanner Crab	Present
King Crab	Present in Southern Prince William Sound
Dungeness Crab	Absent
Shrimp	Traces in Narrows & Eastern Prince William Sound
Scallops	Trace

SOURCE: Maturgo, Zenaida A., *EXPLORATORY FISHERY DRAGS FOR DEMERSAL FISH AND SHELLFISH, GULF OF ALASKA*, Environmental Conservation Department, Shell Oil Company, Houston - information taken from figures, 1972.

FLORA AND FAUNA OF VALDEZ HARBOR AND NARROWS

ANIMALS	Solomon and Sawmill Creeks	Waterfall (7-mile) Creek	Robe and Lowe River flats	Siwash Creek	Mineral Creek	City Limits Creek	Allison Creek	Tideflats at each end of Port Valdez	Kayfan Creek	Solomon Creek	Anderson Bay	Sheep Bay	Gold Creek	City of Valdez	Valdez Narrows	Canyon Slough, Salmon Slough, Pit Creek
FISH																
*Pink salmon (or spawn)	c	f	c	f	f	f	r		f	c	r					c
*Chum salmon (or spawn)	f	f	c	vc	f	vc	f			f	r					c
*Red salmon (or spawn)			vc							.	:					vc
*Coho salmon (or spawn)			c		f											c
Chinook salmon (or spawn)																
Dolly Varden trout			c													
Halibut	f				u										u	
Herring (and eggs)											f				u	
Other bottom fish					u									u	c	
Rockfish					u									u	c	
BIRDS																
*Diving ducks	f-c	f			c			c	f	f	f-c	c	f-c	f	f-c	
*Dabbling ducks			f-c	f-c	f	f-c		c						f		
*Canada geese			c	f-c				f-c								
*Black brant			c	f-c		f-c		f-c								
*Swans			r					f								
*Alcids	c		f		c			c	f	f	f	c	f	f	c	
*Cormorants	c		f		c			c			f	c	f	f	c	
*Other waterfowl (including scoters, puffins, murres, etc.)	c		f	f-c	c	f-c		c	f	f	f-c	c	f-c		c	
Sandpipers	f		c		f-c			f-c			f-c	f-c				
Phalaropes																
Other shorebirds (including plovers, knots, etc.)																
Gulls and terns	f		c		f		c	c			f		f	c	c	
Black-legged kittiwakes												c				
Sandhill cranes			f	r-c		f-c		f-c								
Bald eagles			f		u			c							f	
Crows and ravens	c	f	c		c		c		f	f	c	c	f	c	c	
Other species	f	f	u		f			c		f-c		u			u	
MAMMALS																
Killer whale															f	
Harbor porpoise															f	
Other dolphins and porpoises															u	
*Harbor seals															f	
Northern sea lion															f	
*Sea otter																
*River otter	f		u		u			u	f	u		u				u
Mink					[illegible]			u	f	u		u				u
Other mustelids								u								u
*Black bear	u		u		u			u								u
*Brown bear								u								u
Wolverine								u								u
Other mammals, large and small			f-c					u								u

LEGEND: vc - very common c - common f - few r - rare u - unknown abundance
no entry - organism is not known to be present in the habitat
* especially sensitive ecologically, economically, or publicly

SOURCE: Alyeska Pipeline Servia Co., *401 BIOLOGICAL ENVIRONMENT*, Oil Spill Contingency Plan, Alyeska Marine Terminal, Vol 1 - The Plan, Vo. 2 - Annexe, Woodward-Envicon Inc., Environmental Consultants.

FLORA AND FAUNA OF VALDEZ HARBOR AND NARROWS (CONT'D.)

ANIMALS	Solomon and Sawmill Creeks	Waterfall (7-mile) Creek	Robe and Lowe River Flats	Siwash Creek	Mineral Creek	City Limits Creek	Allison Creek	Tideflats at east end of Port Valdez	Loyden Creek	Solomon Creek	Anderson Bay	Sheep Bay	Gold Creek	City of Valdez	Valdez Narrows	Canyon Slough, Solomon Slough, Pit Creek
ZOOPLANKTON											u	u			u	
INVERTEBRATES																
Snow crabs					f-c			f-c								
*Dungeness crabs	f				f-c			f-c								
Other small crustaceans	f				f-c			f-c								
Softshell clams (*Mya arenaria*)					u			c-vc								
Ducks clams (*Macoma inconspicua*)					u			c-vc								
Bay mussels					vc			c			vc	f-c			vc	
Other bivalves	f				c			c			u				f	
Limpets (*Acmaea* spp.)					c						vc	f			vc	
Periwinkles and other snails					f-c			f			vc	c			vc	
Starfish (several species)					f			f			c				c	
Barnacles					c			f-c			vc	f			vc	
Sponges											f				c	
Sea Anemones					f						f				c	
Polychaete worms	f				vc			vc			f				c	
Sea urchins											u				u	
Numerous small infaunal animals		u	vc	u	vc			vc			f-c				vc	
PLANTS																
ALGAE																
Rockweed (*Fucus distichus*)	f				vc			c			vc	c			vc	
Sea lettuce (*Ulva* spp. and *Monostroma* spp.)					c			c			c				c	
Green algae (*Enteromorpha* spp.)					c			f-c								
Green algae (*Spongomorpha* spp.)															c	
Brown algae (*Laminaria* spp.)											c				c	
Brown algae (*Costaria costata*)											c				c	
Other brown, red, and green algae of several species					f-vc			f-c			vc		u		vc	

LEGEND: vc - very common c - common f - few r - rare u - unknown abundance
no entry - organism is not known to be present in the habitat
* especially sensitive ecologically, economically, or publicly

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS

AREA: Valdez/Valdez Narrows
SUB-AREA: Valdez to Galena Bay
SEASON:
HABITAT: Benthic - Mud/Rocks

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Tanner Crab [1,2] *Chionoecetes bairdi*	High-Med.	Low (High when exposed)	Low	-	Low	High		June-July Molt & bred	Benthl	Adult		Assoc. w/ mud bottoms - abundant deep in Valdez Arm & Narrows & Port Valdez at 180 m
Tanner Crab [1,2] *Chionoecetes bairdi*	High	High	-	-	-	Med.		Apr.-May Hatch	Pelagic	Larvae		Moderately abundant in Jack Bay - common around Pt. Jacksen - Esp. Juv.
Pink Shrimp [1,2] *Pandalus borealis*	High	Low (High if exposed)	Med.	-	Low	High		Molt in Sept.		Adult		Exp. assoc. w/mud bottoms - abunoant deep (200 m) in Valdez Arm & Narrows
								October - eggs natch in May				Many Uvigerous - moderately abundant in Pt. Valdez & in Galena Bay
King Crab [1,2] *Paralithodes camtschatica*	Low	Low	Med.	-	Low	Med.		Feb.-May Molt & copulate	Benthic	Adult		
King Crab [1,2] *Paralithodes camtschatica*	Low	Low	-	-	-	Low		Mar.-May Eggs hatch		Larvae		
Rex Sole [1,2] *Glyptocephalus zachirus*	Med.	Low	Low-0	-	-	Low		Mar.-Apr.	Benthic	Adult		Deepwater species although juveniles are known to occur in shallow waters
Shrimp [1,2] *Crago intermedia*	Med - Low	Low (High when exposed)	-	-	-	Med. - Low		Molt in Sept. Lay eggs in Oct. Eggs hatch in May		Adult		

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Valdez/Valdez Narrows
SUB-AREA: Valdez to Galena Bay
SEASON:
HABITAT: Benthic - Mud/Rocks

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Pacific Ocean Perch [2] *Sebastes alutus*	Low in Valdez area High in P.W. Sound proper	Low	High	-	-	Med.		Sept.-Oct. copulation Mar.-Apr. larvae expelled in deep water	Approx 100 - 500 m	Adult	Planktonic Crustaceans	Comprises 90 percent of total Rockfish catch
Green Sea Urchin [1] *Strongylocentrotus drobachiensis*	Med. - High	High when exp.	Med. (Pot.)	-	-	High		Spring			Diatoms Algae	Esp. assoc. w/rocky bottoms - abundant in Valdez Narrows
Sunstar [1] *Pycnopodia helianthoides*	Med.	Low	-	-	-	Med.-High			Intertidal to 40 m			Exp. assoc. w/rocky bottoms
Coonstripe Shrimp [1] *Pandalus hypsinotus*	High	High (when exposed)	Med.	-	Med.	High						Abundant deep in Valdez Arm & in Pt. Valdez at 180 m and in Galena Bay. Moderately abundant in Jack Bay.
Sea Cucumber [1] *Stichopus californicus*	High	Low	-	-	-	Med.						Abundant deep in Valdez Arm.
Flathead Sole [1] *Hippoglossoides elassodon*	High	Low	Med.	-	-	Med.						Moderately abundant in Galena Bay. Very abundant in Jack Bay.
Yellowfin Sole [1] *Limanda aspera*	High	Low	High	-	-	Med.						Very abundant in Jack Bay.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA Valdez/Valdez Narrows
SUB-AREA Valdez to Galena Bay
SEASON
HABITAT Benthic - Mud/Rocks

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Hermit Crab [1] *Pagurus [illegible]*	High	High (when exposed)	-	-	-	Med.						Abundant in Valdez Narrows.
Hermit Crab [1] *Pandalus montagui tridens*	High	High (when exposed)	Med.	-	-	Med.						Abundant in Pt. Valdez at 240 m.
Ophiura Sp.	High		-	-	-	Med.-High						Abundant in Pt. Valdez at 200 m and 250 m.
Scallop [1] *Pecten* Sp.	High	Low	Low	0	-	Med.						Semi-abundant in Pt. Valdez at 200 m.
Walleye Pollock [1] *Theragra chalcogramma*	High	Low	Med.-High	0	-	High						Abundant (moderately) in Jack Bay.
Shrimp [1] *Crago communis*	High	High (when exposed)	Low	0	Low	High						Moderately abundant everywhere.
Arrowtooth Flounder [1] *Atheresthes stomias*	High	Low	Med.	0	-	Med.						Dominates Frince William Sound Flatfish catches > (49f) or 100 m.
Amphipod [3] *Acanthoptilum ptila*	High to 24g /0.1m	Low (High when exposed)	6	0	0	Med.					Suspension feeder	Conc. in Narrows.
Cerianthid Sp. [3]	Med. to 1.2 g/0.1m	Low (High when exposed)	6	0	0	Med.					Suspension feeder	Conc. in mid Pt. Valdez.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA Valdez/Valdez Narrows
SUB-AREA Valdez to Galena Bay
SEASON
HABITAT Benthic - Mud/Rocks

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Crustacean [3] *Eudorella emarginata*	Med. to 0.08g/0.1m2	Low (High when exposed)	6	0	0	Med.					Selective deposit	Conc. on S. side of Mid-Port.
Crustacean [3] *Pinnixa schmitti*	Med. to 1.6g/0.1m2	Low (High when exposed)	6	0	0	Med.					Scavenger	Conc. in Mid-Port.
Echinoderm [3] *Amphiodia craterodmeta*	Med. to 0.30g/0.1m2	Low (High when exposed)	6	0	0	Med.					Selective deposit	Conc. on S. side of Mid-Port.
Echinoderm [3] *Ctenodiscus crispatus*	Med. to 2.0g/0.1m2	Low (High when exposed)	6	0	0	Med.					Non-selective deposit	Conc. along N. shore of Port.
Brittlestar [3] *Ophiura sarsi*	High to 7g/0.1m2		0	0	0	High					Selective deposit	Conc. deer in Mid-Port and in Narrows constriction.
Gastropod [3] *Cylichna attonsa*	Med. to 0.30g/0.1m2		0	0	0	Low					Predator	Conc. c:f Jackson Pt.
Gastropod [3] *Odostomia* Sp.	Med. to 0.06g/0.1m2		0	0	0	Low					Predator	Conc. (scattered) along shoreline in Port.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA Valdez/Valdez Narrows
SUB-AREA Valdez to Galena Bay
SEASON
HABITAT Benthic - Mud/Rocks

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Scaphopod [3] *Dentalium* Sp.	Med. to 0.8 g/0.1 m2		0	0	0	Low					Selective deposit	Conc. in Narrows and deep in Arm.
Pelecypod [3] *Axinopsida serricata*	Med. to 0.4 g/0.1 m2		0	0	0	Low					Suspension feeder	Conc. throughout Port and deep in Arm.
Cockle [3] *Clinocardium ciliatum*	High to 3.6 g/0.1 m2		0	0	0	High					Suspension feeder	Conc. along S. shore of Port and in Narrows.
Softshell Clam [3] *Macoma calcarea*	High to 7.2 g/0.1 m2		0	0	0	High					Selective deposit	Conc. near Pt. Jackson and in Narrows and Valdez Arm.
Softshell Clam [3] *Mya inconspicua*	Med. to 1.0 g/0.1 m2		0	0	0	Med.					Selective deposit	Conc. at E. end of Port.
Clam [3] *Nuculana minuta*	Med. to 0.04g/0.1 m2		0	0	0	Med.					Selective deposit	Conc. (scattered) throughout Port.
Clam [3] *Yoldia arctica*	High to 3.6 g/0.1 m2		0	0	0	High					Selective deposit	Conc. in and adj. to Narrows and near Pt. Jackson.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA Valdez/Valdez Narrows
SUB-AREA Valdez to Galena Bay
SEASON
HABITAT Benthic - Mud/Rocks

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Clam [3] *Y. thraciaeformis*	Med. to 0.8 8g/0.1 m2		0	0	0	Med.					Selective deposit	Conc. near E. end of Port.
Chiton [3] *Chaetoderma robusta*	Med. to 0.5 g/0.1 m2	Low (High if exposed)	0	0	0	Low					Grazer (Predator)	Conc. uniformly throughout area, esp. E. end of Port.
Phyllodocid [3] *Eteone barbata*	High-Med. to 2.2 g/0.1 m2	Low (High if exposed)	0	0	0	Low					Predator	Conc. at E. end of Port.
Phyllodocid [3] *Phyllodoce maculata*	Med. to 0.1 g/0.1 m2	Low (High if exposed)	0	0	0	Low					Predator	Conc. near E. end of Port.
Hesionid [3] *Podarke pugettensis*	Med. to 0.0 2g/0.1 m2	Low (High if exposed)	0	0	0	Low					Selective deposit	Conc. near E. end of Port.
Nephthydid [3] *Nephthys ciliata*	High to 6.0 g/0.1 m2	Low (High if exposed)	0	0	0	High					Predator	Abundant throughout area.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA Valdez/Valdez Narrows
SUB-AREA Valdez to Galena Bay
SEASON
HABITAT Benthic - Mud/Rocks

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Glycerid [3] *Glycera nana*	Med. to 0.44g/0.1 m2	Low (High if exposed)	0	0	0	Med.					Predator	Clustered throughout area, esp. in narrows.
Goniadid [3] *Goniada annulata*	Med. to 0.92g/0.1 m2	Low (High if exposed)	0	0	0	Low						Conc. between Pt. Jackson and New Valdez and deep in Valdez Arm.
Lumbrinzreid [3] *Lumbrineris similabris*	High to 3.0 g/0.1 m2	Low (High if exposed)	0	0	0	Med.						Abundant throughout area.
Orbinid [3] *Haploscoloplos panamensis*	Med. to 1.2 g/0.1 m2	Low (High if exposed)	0	0	0	Low						Clustered throughout area.
Paraonid [3] *Aricidea suecica*	To 0.03g/0.1 m2	Low (High if exposed)	0	0	0	Low						Clustered throughout Port and Arm.
Spionid [3] *Prionospio malmgreni*	Med. to 0.06g/0.1 m2	Low (High if exposed)	0	0	0	Med.						Spread throughout Port.
Cirratulidae [3] *Chaetozone setosa*	Med. to 0.12g/0.1 m2	Low (High if exposed)	0	0	0	Med.						Clustered throughout Port, esp. between Pt. Jackson and Valdez.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Valdez/Valdez Narrows
SUB-AREA: Valdez to Galena Bay
SEASON:
HABITAT: Benthic - Mud/Rocks

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Cossura longicirrata [3]	Med. to 0.18g/0.1m2	Low (High if exposed)	0	0	0	Med.						Clustered in E. end of Port.
Tharix monilaris [3]	Med. to 0.06g/0.1m2	Low (High if exposed)	0	0	0	Med.						Clustered throughout Port, esp. around Pt. Jackson.
T. parvus [3]	Med.-Low 0.01g/0.1m2	Low (High if exposed)	0	0	0	Med.						Clustered through area, esp. around Pt. Jackson.
Sternaspid [3] *Sternaspis scutata*	Med.-Low 0.01g/0.1m2	Low (High if exposed)	0	0	0	Med.						Clustered throughout area, esp. around Pt. Jackson and deep in Arm.
Capitellid [3] *Heteromastus filiformis*	High to 4.0g/0.1m2	Low (High if exposed)	0	0	0	High						Spread throughout area, esp. conc. in E. end of Port.
Maldanid [3] *Praxillella gracilis*	Med. to 1.8g/0.1m2	Low (High if exposed)	0	0	0	Med.						Clustered throughout area, esp. near Narrows.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Valdez/Valdez Narrows
SUB-AREA: Valdez to Galena Bay
SEASON:
HABITAT: Benthic - Mud/Rocks

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Ampharetid [3] *Amphicteis scaphobranchiata*	High to 4.0g/ 0.1m2	Low (High if exposed)	0	0	0	High						Conc. in Port, esp. between Mineral Creek and Valdez.
Lysippe labiata [3]	Med. to 0.1g/ 0.1m2	Low (High if exposed)	0	0	0	Med.						Conc. around Pt. Jackson.
Melinna cristata [3]	High to 3.6g/ 0.1m2	Low (High if exposed)	0	0	0	Med.						Conc. near shores in E. end of Port and deep in Valdez Arm.
Terebellid [3] *Pista cristata*	High to 3.0g/ 0.1m2	Low (High if exposed)	0	0	0	Med.						Conc. in Narrows and near Pt. Jackson.
Sabellid [3] *Myxicola infundibulum*	Med. to 0.7g/ 0.1m2	Low (High if exposed)	0	0	0	Med.						Conc. in mid Port, esp. adj. to Sawmill Creek.
Starfish [4] *Evasterias troschelli*									Intertidal to 6m			

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA Valdez/Valdez Narrows
SUB-AREA Valdez to Galena Bay
SEASON
HABITAT Benthic - Mud/Rocks

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Banded Snails [4] *Lacuna* Sp.	Common	High	-	-	-	Med.			Shallow subtidal			Common at Jackson Point.
Sea Anemone [4] *Metridium senile*	Common		-	-	-	Low						
Crab [5] *Scyra* Sp.	Common	(High if exposed)	-	-	-	Low						Common at Jackson Point.
Linocod [5] *Ophiodon ophiodon*	Low	Low	-	-	High	Low-Med.						Rarely caught.
Threespine [5] Stickleback *Gasterosteus aculeatus*	Med.-High	Med.-Low	-	-	-	High						
Pacific Halibut [5] *Hippoglossus stenolepis*	Low	Low	Low	-	Low	High						
Acorn Barnacle [1] *Balanus glandula*	Med. to 250/m 2	Med.	0	0	0	Med.			Intertidal			Aue. biomass for habitat animals 400-530 gm/m^2 - Margalef diversity index = 1.9-1.8 - 14 species.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Valdez/Valdez Narrows
SUB-AREA:
SEASON:
HABITAT: Low to moderate profile Rock & shingle intertidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
California Mussel[1] *Mytilus californicus*	Med. to 400/m2	High	0	0	0	Med.			Inter-tidal			
Limpet *Notoacmea (Acmea)* Sp.[1]	Low to 40/m2	Med.	0	0	0	Med.			Inter-tidal			
Sitka Periwinkle[1] *Littorina sitkana*	High to 2000/m2	Med.-Low	0	0	0	Med.			Inter-tidal			
Hermit Crab[1] *Pagurus hirsutiusculus*	Low	High	0	0	0	Med.			Inter-tidal			
Isopod[1] *Exosphaeroma oregonensis*	Low	High	0	0	0	Med.			Inter-tidal			
Shore Crab[1] *Hemigrapsus oregonensis*	Low	Low	0	0	0	Med.			Inter-tidal			

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Valdez/Valdez Narrows
SUB-AREA:
SEASON:
HABITAT: Steep Rock Intertidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE				ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY			REMARKS
			COMMERCIAL	SUBSISTANCE	RECREATION	ECOLOGICAL			DEPTH RANGE	LIFE HIST. STAGE	FOOD ORGANISMS	
Acorn Barnacle [1] *Balanus glandula*	Med-High to 8000/m2	Med.	0	0	0	Med.						Ave. animal biomass = 750gm/m^2 18 species, Margalef diversity index = 2.3-0.8.
California Mussel [1] *Mytilus californianus*	High-Med. to 2000/m2	High	0	0	0	Med.						
Limpet *Notoacmea (Acmaea)* Sp. [1]	High-Med. 1000 to 250/m2	Med.	0	0	0	Med.						
Sitka Periwinkle [1] *Littorina sitkana*	High to 1600/m2	Med.-Low	0	0	0	Med.						
Hermit Crab [1] *Pagurus hirsutiusculus*	High to 550/m2	High	0	0	0	Med.						
Isopod [1] *Exosphaeroma oregonensis*	Med. to 100/m2	High	0	0	0	Med.						
Shore Crab [1] *Hemigrapsus oregonensis*	Low-M. to 30/m2	Low	0	0	0	Med.						

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA Valdez/Valdez Narrows
SUB-AREA
SEASON
HABITAT Low Profile Sand/Gravel Intertidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Acorn Barnacle [1] *Balanus glandula*	Med. to 450/m2	Med.	0	0	0	Med.						Ave. animal biomass 150 gm/m^2 - 9 animal species; D = 1.6-0.9.
California Mussel [1] *Mytilus californicus*	High to 2000/m2	High	0	0	0	Med.						
Limpet *Collisella (Acmea)* Sp. [1]	Low	Med.	0	0	0	Med.						
Sitka Periwinkle [1] *Littorina sitkana*	High to 900/m2	Med.-Low	0	0	0	Med.						
Hermit Crab [1] *Pagurus hirsutiusculus*	Low	High	0	0	0	Med.						
Isopod [1] *Exosphaeroma oregonensis*	Low	High	0	0	0	Med.						
Shore Crab [4] *Hemigrapsus oregonensis*	Low	Low	0	0	0	Med.						

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA Valdez/Valdez Narrows
SUB-AREA
SEASON
HABITAT Low Profile Sand/Gravel Intertidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Gastropod [4] *Aglaia diomedea*	High	High	-	-	-	Med.						
Clam [4] *Mya arenaria*	High	High	-	-	Low	Med.						
Clam [4] *Macoma inconspicua*	High	High	-	-	Low	Med.						

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA Valdez/Valdez Narrows
SUB-AREA
SEASON
HABITAT Pelagic Waters

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
General Phyto-plankton [1] *Ceratium fusus* *Skeletonema costatum* *Gonyaulax* Sp. *Peridinium* Sp. Diatoms	Med. 1.8x10 2 to 1.3 x 10^5 Organ-isms liter	High	-	-	-	High			Photic Zone			Highest conc. in Narrows and Galena Bay, lowest nearest Valdez. Primary prod. not very high in general exp. Galena Bay and Narrows.
Copepod Juv. & Nauplii [1] *Pseudocalanus* *Acartia*	Med.	High	-	-	-	High			Photic Zone		Phytoplankton	Highest conc. in Narrows and Galena Bay regions, lowest extremes in Valdez vicinity.
Cladoceran Juv. & Nauplii [1]	Med.	High	-	-	-	High			Photic Zone			

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA General Prince William Sound
SUB-AREA
SEASON
HABITAT Intertidal to Sublittoral Gravel Beaches

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Saxidomus giganteus [6]	Max. High 7.3/ft 2	High	Low	-	High	High-Med.						Max. between MLW & LLW.
Protothaca staminea [6]	High 7.7/ ft 2	High	-	-	High	High-Med.						Conc. between -2.0 and -5.0.
Macoma [6]	High 8.7/ ft 2	High	-	-	Low	Med.						Conc. between 1.5 and -3.0.
Humilaria, Mya & Tresus capax [6]	Med. 1.2/ ft 2	High	-	-	-	Med.						Conc. between 0.0 and -3.5.
Clinocardium nuttallii [6]	Med. 0.9/ ft 2	High	-	-	-	Med.-Low						Conc. between -0.5 and -3.5.
Siliqua patula [6]	High	High	Low	-	High	High						Sand beaches - exposed.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA General Prince William Sound
SUB-AREA Olsen Bay
SEASON
HABITAT Rock-Shingle Beach/Tideflat

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS: ROCK-SHINGLE	REMARKS: MUD TIDEFLAT
Polychaetes [7] *Abarenicola pacifica*	Med. 0.5-1.0/¼ m2	High	-	-	-	High						Highest	
Eteone longa [7]	Med. 1.0-3.0/¼ m2	High	-	-	-	High						Highest	
Glycinde picta [7]	Med. 1.0-2.0/¼m2	High	-	-	-	High							Highest
Haploscoloplos elongata [7]	High 2.0-5.5/¼ m2	High	-	-	-	High						Same	
Heteromastus filiformis [7]	High 40-85/¼m2	High	-	-	-	High							Highest
Nephthys ciliata [7]	Med. 1.0-2.0/¼m2	High	-	-	-	High						Similar	
Nereis vexillosa [7]	Med. 2.0-3.0/¼m2	High	-	-	-	High						Highest	

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: General Prince William Sound
SUB-AREA: Olsen Bay
SEASON:
HABITAT: Rock-Shingle Beach/Tideflat

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS: ROCK-SHINGLE	REMARKS: MUD TIDEFLAT
Polychaetes [7] *Nerine cirratulus*	Med. to 1.0/½ m2	High	-	-	-	High						None	Present
Pectinaria granulata [7]	Med. to 2.0-3.0/½ m2	High	-	-	-	High						Common	Uncommon
Echinoderms [7] *Echiurus echiurus alaskanus*	High 2.5-9.0/½ m2	High	-	-	-	High						More abundant	
Cockle [7] *Clinocardium nuttallii*	High to 20-65/½m2	High	-	-	Low	High						Same	
Clam [7] *Macoma inconspicua*	High to 20-70/½m2	High	-	-	Low	High							Highsest
Clam [7] *Macoma inquinata*	High 5-22/½m2	High	-	-	Low	Med.						Highest	
Clam [7] *Macoma nasuta*	Med. 2.0-5.0/½m2	High	-	-	Low	Med.						Similar	

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: General Prince William Sound
SUB-AREA: Olsen Bay
SEASON:
HABITAT: Rock-Shingle Beach/Tideflat

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Clam [7] *Mya arenaria*	Med.-High to 1.5-85/m2	High	-	-	Low	Med.						Highest
Mussel [7] *Mytilus edulis*	High 125-375/m2	High	-	-	-	High						Highest Uncommon
Littleneck Clam [7] *Protothaca staminea*	High to 5-60/m2	High	-	-	High	Med.-High						Highest
Butter Clam [7] *Saxidomus giganteus*	Med. to 1-18/m2	High	-	-	High	Med.						Highest Uncommon
Limpet [7] *Collisella pelta*	Med. to 5-13/m2	High	-	-	-	Med.-Low						Similar
Limpet [7] *Notoacmea persona*	High to 10-40/m2	High	-	-	-	Med.						Highest Uncommon

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: General Prince William Sound
SUB-AREA: Olsen Bay
SEASON:
HABITAT: Rock-Shingle Beach/Tideflat

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Periwinkles [7] *Littorina scutulata*	High to 200-600/ m2	High	-	-	-	High						Highest Uncom[illegible]
Periwinkles [7] *L. sitkana*	High to 20-120 /m2	High	-	-	-	High						Highest
Barnacle [7] *Balanus balanoides*	High to 200-1600/ m2	High	-	-	-	High						Highest
Isopods [7] *Exosphaeroma oregonensis*	Med. to 4-17/ m2	High	-	-	-	Med.						Highest
Idothea [7] *wosnesenskii*	Med. to 1-6.5/ m2	High	-	-	-	Med.						Highest

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: General Prince William Sound
SUB-AREA: Olsen Bay
SEASON:
HABITAT: Rock-Shingle Beach/Tideflat

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Hermit Crab [7] *Pagurus hirsutiusculus*	Med. to 4-18/km^2	High	-	-	-	High						Highest
Shore Crab [7] *Hemigrapsus oregonensis*	1-45/km^2	Med.-Low	-	-	-	High						Highest Uncommon

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Prince William Sound
SUB-AREA: Knight Island, Drier Bay
SEASON: Summer
HABITAT: Gravel, Mud, Sand, Eelgrass; Intertidal & shallow Subtidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Charys hericeus 8	Med.	Low	Low-None	-	Low	Med.						Fairly common on stony bottom.
Limatula subauriculata 8	Med.-High	Low	Low-None	-	-	Med.						Quite common; 30 f.
Monia macrochisma 8	Med.	Med.-High	Low-None	-	-	Med.						Common on rocks at low tide.
Mytilus edulis 8	High	High	Low-None	-	Low	High						Very common.
Modiolus modiolus 8	High	High	Low-None	-	-	Med.						Very common.
Musculus vernicosus 8	High	High	Low-None	-	-	Med.						Very common; attached to eelgrass.
Crenella decussata 8	Med.	High	Low-None	-	-	Med.						Common on roots of eelgrass.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Prince William Sound
SUB-AREA: Knight Island, Drier Bay
SEASON:
HABITAT: Gravel, Mud, Sand, Eelgrass, Intertidal & Shallow Sub-Tidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Astarte alaskensis [8]	Med.	Low	Low-None	-	-	Med.						Common; 10 to 40 fathoms.
A. rictocyma esquimalti [8]	Med.	Low	Low-None	-	-	Med.						Common; dredged.
Thyasira gouldii [8]	Med.	Low	Low-None	-	-	Med.						Common; dredged.
Diplodonta aleutica [8]	Med.	Med.-High	Low-None	-	-	Med.						Under stones at low tide.
Parvilucina tenuisculpta [8]	Med.	Low	Low-None	-	-	Med.						Common; dredged.
Saxidomus giganteus [8]	High	High	Low-None	Low	Med-High	Med.						Very common on sandy beaches.
Protothaca staminea [8]	Med.-High	High	Low-None	Low	Med.-High	Med.						Common on muddy, stony beaches.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Prince William Sound
SUB-AREA: Knight Island, Drier Bay
SEASON: Summer
HABITAT: Gravel, Mud, Sand, Eelgrass, Intertidal & Shall Subtidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Macoma sitkana [8]	High	High	Low-None	-	Low	Med.						On muddy beaches.
M. nasuta [8]	High	High	Low-None	-	Low	Med.						On muddy beaches.
M. balthica [8]	High	High	Low-None	-	Low	Med.						Very common on muddy beaches.
Mya intermedia [8]	Med.-High	High	-	-	-	Med.-Low						Fairly common on muddy beach; young.
Saxicava arctica [8]	High	High	-	-	-	Med.-Low						Very common on old wood piles and submerged and floating wood.
S. pholadis [8]	Med.	High	-	-	-	Med.-Low						Less common on old wood piles and submerged and floating wood.
Bankia setacea [8]	Med.	High	-	-	-	Med.-Low						Intertidal and shallow subtidal.
Cadulus hepburni [8]	Med.	High	-	-	-	Med.-Low						Common below low tide mark.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA Prince William Sount
SUB-AREA Knight Island, Drier Bay
SEASON Summer
HABITAT Gravel, Mud, Sand, Eelgrass, Intertidal and Shallow Subtidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Acteocina eximia [8]	Med.	Low	-	-	-	Med.-Low						Common on eelgrass roots.
Retusa semen [8]	High	High	-	-	-	Med.-Low						Dredged frequently.
Haminoea olgae [8]	Med.	Low	-	-	-	Med.-Low						Very common on eelgrass.
Lora shiachiana [8]	Med.-High	Low	-	-	-	Med.-Low						Dredged; not uncommon.
Admete couthouyi [8]	High	High	-	-	-	Med.-Low						Dredged; quite common.
Searlesia dira [8]	High	High	-	-	-	Med.-Low						Very common on rocky beaches.
Thais lamellosa [8]	Med.	High	-	-	-	High-Med.						Very common on rocks at high tide.
T. lima [8]	Med.	High	-	-	-	High-Med.						Common on rocks.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Prince William Sound
SUB-AREA: Knight Island. Drier Bay
SEASON: Summer
HABITAT: Gravel, Mud, Sand, Eelgrass, Intertidal & Shallow Subtidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
T. emarginata [8]	Med.	High	-	-	-	High-Med.						Common, rocks.
Cypraeolina pyriformis [8]	Med.	High	-	-	-	Med.-Low						Fairly common on seaweeds.
Bittium vancouverense [8]	Med.	High	-	-	-	Med.-Low						Common at low tide.
Trichotropis cancellata [8]	Med.	Low	-	-	-	Med.-Low						Dredged; common.
T. insignis [8]	Med.	Low	-	-	-	Med.-Low						Dredged; common.
Tachyrhynchus erosus major [8]	Med.	Low	-	-	-	Med.-Low						Dredged; common.
Littorina sitkana [8]	High	High	-	-	-	Med.-High						Very common on rocks.
L. rudis [8]	High	High	-	-	-	Med.-High						Very common on rocks.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Prince William Sound
SUB-AREA: Knight Island, Drier Bay
SEASON: Summer
HABITAT: Gravel, Mud, Sand, Eelgrass, Intertidal & Shallow Subtidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	COMMERCIAL	SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
L. scutulata [8]	Med.	High	-	-	-	Med.-High						Common on rocks.
Lacuna divaricata [8]	High	High	-	-	-	Med.						Very common on eelgrass.
Alvania reticulata [8]	Med.	High	-	-	-	Med.						Common on eelgrass roots.
Natica aleutica [8]	Med.	Low	-	-	-	Med.						Dredged; common.
Lepeta concentrica [8]	Med.	Med-High	-	-	-	Med.						Common at low tide on rocks.
L. caecoides [8]	Med.	Med-High	-	-	-	Med.						Common at low tide under stones.
Acmaea pelta [8]	Med.	High	-	-	-	Med.-High						Common.
Pupillaria pupilla [8]	High	High	-	-	-	Med.						Very common at low tide.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Prince William Sound
SUB-AREA: Knight Island, Drier Bay
SEASON: Summer
HABITAT: Gravel, Mud, Sand, Eelgrass, Intertidal & Shallow Subtidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Margarites helicinus [8]	High	High	-	-	-	Med.						Very common on eelgrass.
M. marginata [8]	High	High	-	-	-	Med.						Very common on eelgrass.
Siphonaria thersites [8]	Med.	High	-	-	-	Med.						Common on Fucus.
Laqueus californicus [8]	Med.	Low	-	-	-	Med.						Dredged, young; common.
Terebratalia caurina [8]	Med.	Low	-	-	-	Med.						Dredged, young; common.
Spirorbis Sp. [8]	High	High	-	-	-	Med.						Very common on Fucus and eelgrass.
Argobuccinum oregonense [8]	High	Med.-High	-	-	-	Med.-High						Very abundant.
Buccinum morchianum [8]	Med.	High	-	-	-	Med.						Common under rocks.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

AREA: Prince William Sound
SUB-AREA: Knight Island, Drier Bay
SEASON: Summer
HABITAT: Gravel, Mud, Sand, Eelgrass, Intertidal & Shallow Subtidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Tonicella submarmorea [8]	Med.	Low	-	-	-	Med.-Low						Dredged; common.
Ischnochiton interstinctus [8]	Med.	Low	-	-	-	Med.-Low						Dredged; common.
Tonicella lineata [8]	Med.	Med.-High	-	-	-	Med.-Low						Under stones; common.
Mopalia mucosa [8]	Med.	Med.-High	-	-	-	Med.-Low						Under stones.

BIOLOGICAL RESOURCES OF VALDEZ HARBOR/NARROWS (CONT'D.)

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. Hood, D. W., *BASELINE DATA SURVEY FOR VALDEZ PIPELINE TERMINAL ENVIRONMENTAL DATA SURVEY, PART I AND II*, University of Alaska, Institute of Marine Sciences, 240 pp., 1969.

2. Alyeska Pipeline Service Co., *OIL SPILL CONTINGENCY PLAN, ALYESKA MARINE TERMINAL, VOL. 1: THE PLAN, VOL. 2: ANNEXES*, prepared by Woodward-Enviricon, Inc., San Francisco, Calif. - Draft of Section 401 - Biological Environment.

3. Hood, D. W., W. E. Shiels, and E. J. Kelley, *ENVIRONMENTAL STUDIES OF PORT VALDEZ*, University of Alaska, Institute of Marine Sciences, 498 pp., 1973.

4. Alyeska Pipeline Service Co., *OIL SPILL CONTINGENCY PLAN, ALYESKA MARINE TERMINAL, VOL. 1: THE PLAN, VOL. 2: ANNEXES*, prepared by Woodward-Enviricon, Inc., San Francisco, Calif. - Draft of Section 401 - Biological Environment.

5. Smith, R. L., C. P. McRoy, and S. Stoker, *BIOLOGICAL STUDIES, BASELINE DATA SURVEY FOR VALDEZ PIPELINE TERMINAL*, University of Alaska, IMS Report No. R69-17, D. W. Hood, ed., 1969.

6. Baxter, R. E., "Earthquake Effects on Clams of Prince William Sound," *THE GREAT ALASKA EARTHQUAKE OF 1964 - BIOLOGY*, National Academy of Sciences, Wash. D. C., Pub. No. 1604, 1971.

7. Hubbard, J. D., "Distribution and Abundance of Intertidal Marine Invertebrates of Olson Bay, Prince William Sound, One Year After the 1964 Earthquake," *THE GREAT ALASKA EARTHQUAKE OF 1964 - BIOLOGY*, National Academy of Sciences, Wash. D. C., Pub. No. 1604, 1971.

8. Eyerdam, W., "Marine Shells of Drier Bay, Knight Island, Prince William Sound, Alaska," *NAUTILUS*, 38:22-28.

VALDEZ VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1,2]	Grass Flats Estuaries	Low population this part of Game Unit 6; 361 killed 1961 to 1971, high of 63 in 1968.
Black Bear[1,2]	Grass Flats Estuaries	Estimated 8 to 10 per square mile in prime habitats. Rare glacier color phase occasionally encountered. This may one day be classified as rare and endangered.
Goats[2]		Present in area but not likely to be directly impacted by a spill.
Wolves and Wolverines[1]	Low Shore Areas	Both species sparse in area. Wolf population may increase with enlarged moose population.
Moose[1]	Willow Flats	Only contact is at head of Valdez Bay.
Harbor Seal[1]	Beaches	No firm population estimates. Many local concentration areas exceeding 1,000 per area. Formerly harvested - currently protected by Marine Mammal Protection Act. Sensitive to spills.
Northern Fur Seal[3]		Migrant animals.
Sea Lion[1]	Rocky Coves Beaches	Many rookery areas in Sound: 3 in map area, Perry Island 50, The Needle 200, and Knowles Head 200. Adjacent areas even greater numbers.
Sea Otter[1]	Nearshore Area	Present around most outer Prince William Sound Islands. Populations increasing and expanding from former reduced state. Estimated Unit 6 population near 5,000 animals.
Aquatic Furbearers	Nearshore Fresh and Salt Water Areas	Sensitive to spills.
Whales and Porpoises[1]	Open Seas	Dall and Harbor porpoises common in Sound. Killer and minke whales present in outer waters of Sound. Many use Knight Island Passage and Montague Strait during July.
Blacktail Deer[1,2]	Beaches	There are 700 to 1,200 harvested in Unit 16 per year. Beach foraging an important factor during Winter. Deer confined to beach area during entire Winter.
Ducks[1]	Nearshore Waters Beaches Marshes Estuaries	FWS estimates 1,600 Summer population of mallards. Winter population several times greater and includes many other species; 2,800 Summer Scoter ducks, 7,000 merzansers, etc.
Geese[1,2]	Beaches Marshes	FWS estimates 2,500 Summer population of geese in Prince William Sound, mainly Dusky and Vancouver forms (rare).

VALDEZ VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Swans[1, 2]	Beaches Open Water Marshes Estuaries	One-half of world population of trumpeters thought to nest in Copper River drainage. Doubtless some nesting and use in area of impact.
Seabirds[1, 2]	Rocky Cliffs Open Sea	FWS estimates the following Summer populations: gulls 100,000, kittiwakes 58,000, alcids 48,000, Arctic terns 22,000, cormorants 16,000, shearwaters 10,000, loons 2,500, grebes 1,000. Seabird colonies at Glacier Island and Shoup Glacier.
Shorebirds[2]	Beaches Mud Flats	Possible impact on food organisms.
Upland Game Birds[2]		
Raptors[2]		

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

3. Fay, James A., *THE SPREAD OF OIL SLICKS ON A CALM SEA*, Department of Mechanical Engineering, Massachusetts Institute of Technology, Fluid Mechanics Laboratory, Publication No. 69-6, August 1969.

CLIMATOLOGICAL DATA FOR PRINCE WILLIAM SOUND REGION (CORDOVA)

CORDOVA, ALASKA (M..e 13 Airport), 60°30'N., 145°30'W., Elevation (ground) 40 feet. WB-61

Month	Air temperature (°F.) Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extreme: Record highest	Extreme: Record lowest	Precipitation (inches): Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	Humidity (percent): 8:00 a.m. local time	2:00 p.m. local time	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				18	18		18	18	16	16					16	16	16	16	18	16	18	16
Jan.	32.4	17.6	25.0	58	-27	7.05	2.66	24.[illegible]	82	81	3.8	E			7.2	7	4	20	17	7	0	2
Feb.	34.6	17.5	26.1	49	-33	5.27	3.42	23.[illegible]	82	78	4.2	E			7.2	6	4	18	15	7	0	1
Mar.	37.[illegible]	22.7	30.1	52	-24	5.92	2.56	22.[illegible]	82	74	4.3	E			7.1	7	5	19	18	6	0	1
Apr.	43.8	26.9	[illegible].4	65	[illegible] 9	5.07	2.60	11.[illegible]	78	70	4.5	ESE			7.5	6	4	20	15	4	0	1
May	50.4	35.3	42.9	77	20	6.44	2.68	1.[illegible]	85	72	4.4	E			8.4	3	4	24	20	*	0	2
June	57.4	41.2	49.3	79	28	4.19	2.79	[illegible]	8[illegible]	76	3.8	SW			8.4	2	5	23	16	0	*	1
July	60.1	46.4	53.3	84	34	6.44	6.60	[illegible]	8[illegible]	79	3.3	E			8.7	2	4	25	19	0	*	1
Aug.	61.3	45.5	53.4	80	30	9.72	3.94	[illegible]	8[illegible]	79	3.2	E			8.2	3	5	23	19	0	*	2
Sep.	55.7	40.2	48.0	71	20	15.47	7.92	[illegible]	8[illegible]	78	4.3	E			8.2	3	4	23	20	0	*	1
Oct.	47.[illegible]	33.9	40.8	70	1[illegible]	15.56	6.[illegible]	2.[illegible]	8[illegible]	76	4.8	E			8.[illegible]	4	4	23	21	1	*	*
Nov.	38.2	23.9	31.1	55	-17	10.55	4.4[illegible]	[illegible]	8[illegible]	83	4.6	E			8.0	4	4	22	19	4	*	*
Dec.	34.1	19.1	26.6	47	19	6.66	4.65	29.[illegible]	85	83	4.3	E			7.9	5	4	22	19	8	*	1
Year	46.1	31.0	38.6	84	33	98.04	7.9[illegible]	126.[illegible]	84	78	4.2	E			7.9	52	51	262	216	37	2	12

SOURCE: U. S. Department of Commerce and Coastal and Geodetic survey, *PACIFIC AND ARCTIC COASTS - ALASKA, CAPE SPENCER TO BEAUFORT SEA*, Seventh Edition (October 3, 1974), U. S. Coast Pilot Volume 9.

WIND SPEED AT JACKSON POINT AND VALDEZ AIRPORT

% Freq. Wind Speed above Indicated Value	Jackson Point Wind Speed MPH (1)	Probable Direction Of Wind (1)	Valdez Airport Wind Speed MPH (2)	Probable Direction Of Wind (2)
1	32	E or ESE	26	NE or ENE
5	20	E	17	E or ENE
10	12	E	11	E or ENE
25	4	Variable	5	Variable
50	3	Variable	3	Variable
80	calm		calm	

(1) Percentage frequency of wind speed and direction at Jackson Point, 2/71-11/71 and 3/72-7/72, 24 hourly observations per day, MRI charts processed by University of Alaska, Geo. Inst.

(2) U. S. Department of Commerce, ESSA, 1968 Wind Directions versus Wind Speed Tabulation, Valdez Airport, Alaska, 8am - 4 pm, 1963-67.

SOURCE: Alyeska Pipeline Service Co., *402 METEOROLOGY*, Oil Spill Contingency Plan, Alyeska Marine Terminal, Vol. I -The Plan, Vol. 2 - Annexes, Woodward-Envicon Inc., Environmental Consultants.

DATA PROCESSING DIVISION
ETAC/USAF
AIR WEATHER SERVICE/MAC

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND
DIRECTION AND SPEED
(FROM HOURLY OBSERVATIONS)

26410 (STATION) CORDOVA ALASKA MILE 13 APT (STATION NAME) 46-70 (YEARS) ALL (MONTH)

ALL WEATHER (CLASS) ALL (HOURS (L.S.T.))

(CONDITION)

SPEED (KNTS) DIR.	1-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	≥56	%	MEAN WIND SPEED
N	1.3	1.5	.5	.2	.0	.0						3.5	5.0
NNE	.9	1.0	.4	.2	.0	.0	.0	.0				2.5	5.7
NE	1.7	1.8	.8	.2	.0	.0						4.6	5.0
ENE	1.7	3.4	2.4	.8	.1	.0	.0					8.4	6.3
E	2.4	4.4	4.5	2.2	.3	.1	.0	.0	.0			13.8	7.4
ESE	.9	2.3	3.7	2.7	.5	.1	.0	.0		.0		10.2	9.2
SE	.9	1.5	1.6	.8	.1	.0	.0	.0				4.9	7.4
SSE	.3	.6	.6	.2	.0	.0						1.7	6.5
S	.5	.8	.5	.1								1.8	5.4
SSW	.4	.7	.5	.0	.0							1.6	5.6
SW	.7	1.2	.9	.1	.0	.0						3.0	5.8
WSW	.4	.9	.7	.1	.0							2.0	6.1
W	.6	1.0	.5	.1	.0							2.2	5.4
WNW	.5	.6	.4	.1	.0							1.5	5.5
NW	.8	.8	.2	.0	.0							1.8	4.2
NNW	.7	.8	.3	.1	.0	.0						1.9	5.0
VARBL													
CALM												34.0	
	14.7	23.4	18.5	8.0	1.0	.2	.0	.0	.0	.0		100.0	4.4

TOTAL NUMBER OF OBSERVATIONS 181534

SOURCE: National Climatic Center, *SSWO (PART C - SURFACE WINDS)*.

USAFETAC FORM JUL 64 0-8-5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

DRIFT RIVER: INFORMATIONAL RESOURCES

- Drift River Salmonid Resources
- Fish and Shellfish Important in Cook Inlet
- Fish and Shellfish Important at Cook Inlet Determined From National Marine Fisheries Service
- Biological Resources of Drift River
- Drift River Vicinity Mammals and Birds
- Climatological Data - Cook Inlet
- Cook Inlet - Surface Winds
- Climatological Summary - Anchorage
- Surface Winds - Anchorage
- Surface Winds - Kenai
- Surface Winds - Soldotna

DRIFT RIVER SALMONID RESOURCES

Commercial catches in the statistical area including the spill site are large compared to Port Graham and Kamishak Bay. The timing would be similar but a little later (or one week). Comments for juveniles at Port Graham and Kamishak Bay would also be true here. The mean catches (1965-1971) for the Drift River area are given below:

	CATCH IN THOUSANDS	RANGE
Sockeye	245.8	120.1 - 479.8
Pink	57.8	2.4 - 192.8
(even year)	123.8	78.3 - 192.8
Chum	144.1	75.8 - 254.2
Coho	46.5	28.3 - 77.1
King	3.8	.3 - 7.1

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. International North Pacific Fisheries Commission. Statistical Yearbook (for the years stated).

2. Alaska University, *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U. S. Department of Commerce, COM-73-10337, August 1972.

FISH AND SHELLFISH IMPORTANT IN COOK INLET[1]

Halibut
Flathead Sole
Yellowfin Sole
Rock Sole
Sand Sole
Starry Flounder
Butter Sole
Herring
Cottids
Osmerids
King Crab
Tanner Crab
Dungeness Crab
Shrimp
Razor Clams

Trawl catches include halibut, turbot, flathead sole, yellowfin sole, rock sole, sand sole, starry flounder, butter sole, with other species which included cottids, tom cod, greenling and herring, also king crab, tanner crab and Dungeness crab.

Alaska landing statistics report over 4-million pounds of king crab. Season starts in August with largest landings and continues through March.

Dungeness crab landing vary from year to year, landings reported from June through October.

Tanner crab about 2-million pounds taken from November through July.

Shrimp landing over 5-million pounds. Landing nearly equal every month except March, April and May.

Razor clam spawn from late July through August near Homer in Cook Inlet waters of 13.9°C. They set in about eight weeks.[2] McMullen[3] found young clams of 30-40 mm in April 1965 and thought they were from 1964 year class. Increasing sport fishery; little commercial fishery.

HALIBUT

Commercial halibut fishing is of relatively minor importance in Cook Inlet but is increasing with the small boat fleet in the area. This area is the most important fishing area of the selected spill sites. The offshore waters in the Gulf of Alaska are in the center of the high producing areas. Juvenile halibut utilize the shallow areas of lower Cook Inlet as a nursery area.

FISH AND SHELLFISH IMPORTANT IN COOK INLET (CONT'D.)

HERRING

Landings of 1,500 tons of herring for roe were reported from Kachemak Bay and Resurection Bay in 1970.[4]

OSMERIDS

Capelin (*Mallotus villosus*) larvae have been collected during May. Smelt probably utilize the gravel beaches for spawning. Adhesive eggs are spawned at the water's edge at high tide.

SANDLANCE

Larvae collected during May.

SAND SOLE

Sand sole eggs were abundant in Puget Sound from January through March. Metamorphosis complete at a size of 27 mm; no time given.[5]

Sand sole fed 67 percent on herring, 24 percent on other fishes, and 9 percent on larger invertebrates.[6]

SOURCES:

1. Best, E. A., Personal Communication; International Pacific Halibut Commission, Tech. Report 12:63 p., and International Pacific Halibut Commission, Tech. Report 11:32 p.

2. Weymouth, F. W., H. C. McMillin, and H. B. Holmes, "Growth and Age of Maturity of the Pacific Razor Clam, *Siliqua patula* (Dixon)," *U. S. Bur. Fish., Fish. Bulle.*, 41:205-236, 1925.

3. McMullen, J. C., "Some Aspects of the Life History of Razor Clams, *Siliqua patula* (Dixon) in Cook Inlet Alaska," *ALASKA DEPT. OF FISH AND GAME, INFORM. LEAFL. 110*, 18 pp., 1967.

4. Olson, J. M., "Herring Roe: Alaska's Fast Growing Specialty Food Fishery," *COMM. FISH. REV.*, 32(7):45-48, 1970.

5. Heckman, C. P., Jr., "The Larval Development of the Sand Sole *(Psettichthys melanostictus)*," *WASH. DEPT. FISH. FISH. RES. PAPERS*, 2(2):38-47, 1959.

6. Miller, B. S., "Stomach Contents of Adult Starry Flounder and Sand Sole in East Sound, Washington," *J. FISH. RES. BD. CANADA*, 24(12):2515-2526, 1966.

FISH AND SHELLFISH IMPORTANT AT COOK INLET DETERMINED FROM NATIONAL MARINE FISHERIES SERVICE DATA

	ABUNDANCE/PRESENCE
FISH	
Rockfish	Trace - lower Inlet
Pacific Halibut	Traces - off Kachemak and Kamishak Bays
Other Flatfish	Traces - off Kachemak and Kamishak Bays
Sablefish	Traces - in mouth of Inlet
SHELLFISH	
Tanner Crab	Present - lower Inlet
King Crab	Present - lower Inlet
Dungeness Crab	Absent
Shrimp	Traces - in Kachemak and Kamishak Bays
Scallops	Traces - in mouth of Inlet

SOURCE: Maturgo, Zenaida A., *EXPLORATORY FISHERY DRAGS FOR DEMERSAL FISH AND SHELLFISH, GULF OF ALASKA*, Environmental Conservation Department, Shell Oil Company, Houston - information taken from figures, 1972.

BIOLOGICAL RESOURCES OF DRIFT RIVER

AREA: Cook Inlet
SUB-AREA: Drift River
SEASON:
HABITAT: Pelagic - Shallows

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Diatoms 1,2,3,4,5 *Bacillariophyceae*	Med.	High	-	-	-	High	-		Photic Zone	-	-	
General Zooplankton	Med.	High	-	-	-	High	-					
Copepoda (6 Taxa)	Med.	High				High						
Amphipoda (3)	Med.	High	-	-	-	High	-					
Mysidacea (4)	Med.	High	-	-	-	High	-					
Decapoda (5)	Med.	High	-	-	-	High	-					
Annelida (6)	Med.	High	-	-	-	High	-					
Ectoprocta (5)	Med.	High	-	-	-	High	-					
Pacific Herring *Clupea harengus pallasi*	Med. to High	High (Esp. as Larvae)	High	-	-	High		Spring		Adult		Inshore in Spring and Summer Up to 20,000,000 annually Most abundant in Kachemak Bay
Eulachon *Thaleichthys pacificus*	Med.	High	Low	Low	High	High	-	May		Spawning Adults		Anadromous
King Crab *Paralithodes camtschatica*	Low	Low	High	-	Med.	Med.		February to May Molt and Copulate		Adults		

BIOLOGICAL RESOURCES OF DRIFT RIVER (CONT'D.)

AREA: Cook Inlet
SUB-AREA: Drift River
SEASON: Pelagic - Shallows
HABITAT:

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	SUBSISTANCE	RECREATION	ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HIST. STAGE	FOOD ORGANISMS	REMARKS
King Crab *Paralithodes camtschatica*	Low	Low	High	Low	Low	Med.		June to July Molt and Breed	Benthic	Adult		
Tanner Crab *Chionoecetes* sp.	Low	Low	High	Low	Low	Med.		June to July Molt and Breed	Benthic	Adult		
Tanner Crab *Chionoecetes* sp.	Low	High	-	-	-	Med.		April to May Hatch	Pelagic	Larvae		
Dungeness Crab *Cancer magister*	Low	High	Low	Low	Med.	High		May to June Breeding		Larvae		
Dungeness Crab *Cancer magister*		High	-	-	-	Med. (Fish Food)		Eggs Laid in Fall Hatch in Spring				

BIOLOGICAL RESOURCES OF DRIFT RIVER (CONT'D.)

AREA: Cook Inlet
SUB-AREA: Drift River
SEASON:
HABITAT: Intertidal - Sand

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
General 1, 2, 3 Intertidal Organisms Colerenterata (4 Taxa)	Medium	Medium	-	Low	Med.	High						
Ectoprocta (4)	Medium	Medium	-	Low	Med.	High						
Gastropoda (6)	Medium	Medium	-	-	*	-						
Lamellibranchia (5)	Medium	Medium	-	-	*	-						
Amphipoda (7)	Medium	Medium	-	-	-	-						
Decapoda (3)	Medium	Medium	-	-	-	-						
Bopoda (4)	Medium	Medium	-	-	-	-						
Razor Clam *Siliqua patula*	Medium to High	High	Low to Medium	Med.	High	Medium		June to August		Adult		1972 - > 400,000 clams harvested by sport diggers. High concentration at Polly Creek and Northeast side Chinitna Bay
Razor Clam *Siliqua patula*	Medium to High	High	-	-	-	-		Eight-Week Period		Larvae		One-half sport effort during May

BIOLOGICAL RESOURCES OF DRIFT RIVER (CONT'D.)

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. Alaska University, *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U. S. Department of Commerce, COM-73-10337, August 1972.

2a. Rosenberg, D. H., D. C. Burrell, K. V. Natarajan, and D. W. Hood, *OCEANOGRAPHY OF COOK INLET WITH SPECIAL REFERENCE TO THE EFFLUENT FROM THE COLLIER CARBON AND CHEMICAL PLANT*, Univ. of Alaska, Institute of Marine Sciences Report IMS-67-3, 80 p., 1969.

2b. Rosenberg, D. H., K. V. Natarajan, and D. W. Hood, *SUMMARY REPORT ON COLLIER CARBON AND CHEMICAL CORPORATION STUDIES IN COOK INLET, ALASKA, PARTS I AND II, NOVEMBER 1968 - SEPTEMBER, 1969*, Univ. of Alaska, Institute of Marine Sciences Report IMS 69-13, 1969.

3. Hood, D. W., K. V. Natarajan, D. H. Rosenberg, and D. D. Waller, *SUMMARY REPORT ON COLLIER CARBON AND CHEMICAL CORPORATION STUDIES IN COOK INLET, ALASKA*, Univ. of Alaska, Institute of Marine Sciences Report, 16 pp., 1968.

4. Murphy, R. S., S. F. Carlson, D. Nyquist, and R. Britch, *EFFECT OF WASTE DISCHARGE ON A SILT-LADEN ESTUARY. A CASE STUDY OF COOK INLET, ALASKA*, Univ. of Alaska, Institute of Water Resources Report IWR 26, 1972.

5. Kinney, P. J., J. Groves, and D. K. Button, *COOK INLET ENVIRONMENTAL DATA. R/V ACONA CRUISE 065 - MAY 21-28, 1968*, Univ. of Alaska, Institute of Marine Sciences Report R-70-2, 1970.

DRIFT RIVER VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1,2]	Beaches Grass Flats Estuaries	Spills spreading to land would impact grass flats and fishes important as food. Garbage from extended cleanup would attract bears and result in conflicts.
Black Bear[1,2]	Beaches Grass Flats Estuaries	Spills spreading to land would impact grass flats and fishes important as food. Garbage from extended cleanup would attract bears and result in conflicts. Both species of bears in dens overwinter.
Moose[1,2]	Willow Flats	Winter concentrations on willow flats.
Caribou[1,2]	Muskeg	Introduced to Kenai in 1965. Herd enlarging. Important wintering and calving area abutting Cook Inlet between Kenai and Salamatof. Principal potential impact would be shore-based cleanup.
Wolves and Wolverines[1,2]	Low Shore Areas	Often high wolf population in Unit 16, which are actively hunted. Main influence on these species is impact on food animals.
Aquatic Furbearers[2]	Beaches Low Flats Estuaries	Species: river otter, mink, muskrat, beaver. All species subject to habitat loss and potential loss of young particularly during Spring denning period.
Other Terrestrial Mammals[2]	Marsh Edges	Potential habitat losses, population losses and indirect impact on predators.
Harbor Seal[1]	Near Shore Areas	Most expected to avoid spills. Spring young volunerable on beaches. Toxic spills most damaging. Heavy concentrations in Nuka Bay and Passage, Port Dick. No estimate available.
Northern Fur Seal[2]		Transient animals only.
Sea Otter[1,2]	Rocky Beaches Coves	Recolonizing from former extirpation. High concentrations Port Dick, Chugach Bay and Port Chatham. Relatively few on west side of Cook Inlet within Game Unit 16. Formerly classed as endangered. Estimated 600 in Unit 16.
Sea Lion[1]	Rocky Beaches Coves	Former population much reduced. Present mainly on east side. Local population highs just off map.
Beluga Whale[1]	Cook Inlet	An estimated 100 to 300 beluga whales frequent Cook Inlet.

DRIFT RIVER VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Ducks[1]	Inshore Areas Marshes Estuaries Offshore and Inshore Potholes	Commercial guiding. Possible long-term habitat damage. FWS estimates 12 breeding ducks per square mile Unit 15 (Kenai), all year use. FWS estimates 32 breeding ducks per square mile Unit 16 (opposite). Heavy migration area. Little overwintering Cook Inlet.
Geese[1,2]	Estuaries Marshes Tide Flats	Comments as per ducks. Additional possibility of nest disturbance due to the sensitivity of geese while nesting.
Swans[1]	Estuaries Marshes Tide Flats	Breeding trumpeter swans relatively abundant (Unit 15). Few breeding trumpeter swans, some whistling swans (Unit 16).
Sandhill Cranes[2]	Tide Flats	Formerly classed as endangered, now lightly hunted.
Seabirds[1]	Beaches Tide Flats	Colony of glaucous gulls on Kalgin Island, other unplotted seabird colonies in Unit 16. Seabird colonies of mixed species on Chisik Island and at Tuxedni Bay and Duck Island.
Shorebirds[1,2]	Beaches Tide Flats	Increasing population of sandhill crane which was formerly classified as endangered. Presently on increase.
Upland Game Birds[2]		
Raptors[2]		

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

CLIMATOLOGICAL DATA - COOK INLET

Station	January Temp[1] Min. Ave.	January Temp. Mean Ave.	January Temp. Max. Ave.	January Total[2] Precip.	January Snow[2]	July Temp. Min. Ave.	July Temp. Mean Ave.	July Temp. Max. Ave.	July Total Precip.	July Snow	Year Temp. Min. Ave.	Year Temp. Mean. Ave.	Year Temp. Max. Ave.	Year Total Precip.	Year Snow	Elev. (feet)	Prev. Wind Direct.	Mean Hourly Wind Speed
Susitna 1932-1947	2.4	12.6	22.8	1.38	14.5	45.5	57.8	70.1	2.55	0.0	24.8	35.6	46.5	28.05	64.2			
Anchorage Airport 1943-1971	3.6	11.4	19.2	0.88	11.7	49.9	57.6	65.3	2.07	0.0	26.9	34.7	42.5	14.83	71.4	114	N	6.6mph
Tyonek *	4.3		19.9	0.80	11.9	50.3		66.0	1.86	0.0	28.1		43.4	14.71	64.8	114	N	7.5mph
Kenai 22 year	3.7	12.7	21.6	1.12	13.4	46.1	53.5	61.0	2.23	0.0	24.5	33.1	41.7	19.91	68.7	86'	N	6.6mph
Kasilof 32 year	3.7	12.2	20.6	1.12	10.4	45.2	55.0	64.8	2.00	0.0	25.3	34.4	43.6	17.77	55.6	80'	N	
Homer 1943-1971	14.0	20.7	27.3	1.73	10.4	44.6	52.4	60.2	1.69	0.0	29.2	36.4	43.6	23.08	55.4	67	NE	6.5mph
Seldovia*	16.1	23.2	28.2	2.3	10.2	48.6	55.8	57.7	1.40	0.0	33.7	41.0	48.2	26.3	50.8	0-30	N	11.5-17.5mph

* Unofficial local records

1 Degrees Fahrenheit

2 Inches

SOURCE: Evans, C. D., *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U. S. Department of Commerce, COM-73-10337, August 1972. (2 copies)

COOK INLET - SURFACE WINDS

Station	Winter		Summer		Fastest Mile**		2nd Fastest Mile	
	Prevailing Direction*	Mean Speed (mph)	Prevailing Direction	Mean Speed (mph)	Direction	Speed (mph)	Direction	Speed (mph)
Talkeetna	N	4.6	S	4	NE	38	N	35
Chickaloon	NE		SW					
Matanuska	NE		SW					
Palmer								
Susitna	N		SW					
Anchorage	N	6	S	7	NE	61	N	44
Sunrise								
Tyonek	N	7.5						
Kenai	N	7.4	SW		N	53		
Cooper Lake								
Moose Pass								
Sterling								
Kasilof	N		SW					
Homer	NE	7	SW	5.5	NE	35	E	32
Seldovia	N	15						

*N - North, NE - Northeast; etc.
**Fastest observed 1-minute values; not gusts (1 mph=0.87 knot=0.45 meters/second)

SOURCE: Swift, W. H., R. E. Brown, L. V. Kinnel, M. M. Orgel, P. L. Petersen, W. W. Waddell, *GEOGRAPHICAL ANALYSIS OF OIL SPILL POTENTIAL ASSOCIATED WITH ALASKAN OIL PRODUCTION AND TRANSPORTATION SYSTEMS*, Pacific Northwest Laboratory, Division of Memorial Institute to the United States Coast Guard, February 1974, Final Report No. CG-D-79-74.

CLIMATOLOGICAL SUMMARY

ANCHORAGE, ALASKA (International Airport). 61°10'N , 149°59'W ; Elevation (ground) 90 feet WB-1961

Month	Air temperature (°F.)					Precipitation (inches)			Humidity (percent)		Wind (knots)			Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days						
	Normal			Extreme												Sunrise to sunset						
	Daily maximum	Daily minimum	Monthly	Record highest	Record lowest	Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	8:00 a. m. Local time	2:00 p. m. Local time	Mean speed	Prevailing direction	Maximum speed and direction			Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				8	8		8	8	8	8	8			8	8	8	8	8	8	8	8	8
Jan.	20.4	5.5	13.0	50	-23	0.78	1.19	8.7	72	71	4.9	NNE		38	6.8	8	4	19	8	3	0	7
Feb.	20.9	10.3	18.6	43	-26	0.58	1.18	10.0	71	65	5.7	N		43	7.0	6	4	18	8	4	0	5
Mar.	33.8	15.7	24.8	47	-22	0.60	0.51	8.8	66	54	5.8	N		60	6.2	10	5	16	6	3	0	1
Apr.	44.2	26.6	35.4	61	8	0.40	0.50	6.2	65	54	6.0	N		58	6.9	6	7	17	6	2	0	1
May	55.0	36.4	45.7	72	27	0.51	0.55	0.0	61	48	7.5	S		53	7.6	4	6	21	5	0	0	*
June	62.8	44.5	53.7	77	33	0.89	1.71	0.0	65	54	6.9	S		53	7.3	3	9	18	7	0	*	*
July	65.4	49.1	57.3	81	39	1.55	2.06	0.0	72	61	6.3	S		42	7.9	3	6	22	14	0	1	*
Aug.	63.9	47.3	55.6	77	34	2.36	1.68	0.0	75	63	5.5	S		39	8.0	3	6	22	14	0	1	1
Sep.	56.3	39.6	48.0	73	20	2.71	1.92	T	78	62	5.1	NNE		40	7.9	4	5	21	15	0	*	2
Oct.	43.2	28.8	36.0	60	-5	1.87	0.88	8.2	75	64	5.3	N		41	7.2	7	5	19	9	3	0	2
Nov.	29.0	15.5	22.3	48	-21	1.00	0.90	14.7	73	71	5.1	NNE		28	7.8	4	4	22	10	4	0	4
Dec.	20.4	7.1	13.8	43	-30	0.84	1.62	15.7	73	72	4.8	NNE		32	7.1	7	4	20	9	4	0	6
Year	43.4	27.2	35.3	81	-30	14.27	2.06	80.4	70	62	5.7	NNE		44	7.3	65	65	235	111	23	2	30

SOURCE: U. S. Department of Commerce and Coastal and Geodetic survey, *PACIFIC AND ARCTIC COASTS - ALASKA, CAPE SPENCER TO BEAUFORT SEA*, Seventh Edition (October 3, 1974), U. S. Coast Pilot Volume 9.

DATA PROCESSING [illegible]
ETAC/USAF
AIR WEATHER SERVICE/ MAC

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND DIRECTION AND SPEED (FROM HOURLY OBSERVATIONS)

STATION	STATION NAME	YEARS	MONTH
26401	ANCHORAGE ALASKA/ELMENDORF AFB	41-53,56-68	ALL

CLASS: ALL WEATHER

CONDITION:

HOURS (L.S.T.): ALL

SPEED (KNTS) DIR.	1-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	≥56	%	MEAN WIND SPEED
N	3.8	4.8	3.4	1.1	.3	.1	.0	.0	.0			13.3	6.7
NNE	2.2	2.3	1.2	.3	.1	.0	.0	.0	.0			[illegible]	5.4
NE	3.3	2.1	.5	.1	.0	.0	.0	.0	.0	.0		[illegible]	4.1
ENE	2.3	1.7	.3	.0	.0	.0	.0					4.2	[illegible]
E	3.0	1.8	.4	.1	.0	.0	.0					[illegible]	3.7
ESE	.9	.6	.2	.1	.0	.0	.0	.0				1.9	[illegible]
SE	[illegible]	1.0	.5	.2	.0	.0	.0	.0				[illegible]	[illegible]
SSE	.6	.7	.6	.4	.1	.0	.0	.0				2.4	7.7
S	1.1	1.3	1.0	.4	.1	.0	.0					[illegible]	6.5
SSW	.6	[illegible]	.7	.3	.1	.0	.0					[illegible]	[illegible]
SW	1.0	1.1	.7	.2	.0	.0						3.1	5.4
WSW	.7	1.1	1.0	.2	.0	.0						[illegible]	6.1
W	1.5	2.5	2.4	.6	.0	.0	.0				–	[illegible]	6.2
WNW	[illegible]	1.1	[illegible]	.2	.0	.0	.0					[illegible]	[illegible]
NW	1.6	2.2	1.6	.5	.1	.1	.0	.0				6.1	6.3
NNW	1.4	2.2	1.9	.7	.2	.1	.0	.0	.0			5.4	[illegible]
VAREL													
CALM												22.7	
	25.8	[illegible]	17.1	5.3	1.1	.4	.1	.0	.0	.0	–	100.0	4.4

TOTAL NUMBER OF OBSERVATIONS 220129

SOURCE: National Climatic Center, *SSWO (PART C)*.

USAFETAC FORM JUL 64 0-8-5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

DATA PROCESSING DIVISION
ETAC, USAF
ASHEVILLE, N. C. 28801

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND DIRECTION AND SPEED (FROM HOURLY OBSERVATIONS)

26523 (STATION) — KENAI ALASKA FAA (STATION NAME) — 48-67 (YEARS) — ALL (MONTH)

ALL WEATHER (CLASS) — ALL (HOURS (L.S.T.))

(CONDITION)

SPEED (KNTS) DIR.	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥ 56	%	MEAN WIND SPEED
N	1.6	5.6	5.0	4.2	1.1	.4	.1	.0	.0			18.2	8.9
NNE	1.3	5.1	4.7	3.8	.8	.2	.0	.0	.0			16.0	8.8
NE	1.6	3.4	2.0	.7	.0	.0	.0					7.9	5.9
ENE	.6	1.2	.6	.2	.0	.0		.0				2.6	5.8
E	.9	1.5	.4	.1	.0							2.9	4.9
ESE	.5	1.2	.3	.0	.0							2.0	4.9
SE	.8	1.9	.6	.1	.0	.0						3.4	5.1
SSE	.4	1.1	1.0	.4	.1	.0						3.2	7.1
S	.6	2.0	2.7	1.7	.2	.1	.0	.0				7.3	8.6
SSW	.4	1.5	2.9	1.8	.2	.0	.0	.0				6.8	9.0
SW	.3	1.4	2.2	.6	.0	.0	.0					4.6	7.5
WSW	.1	.5	.9	.2	.0	.0						1.7	7.3
W	.2	[illegible]	.5	.1	.0	.0						1.3	6.5
WNW	.1	.5	.4	.0	.0	.0						1.0	6.1
NW	.4	.9	.5	.1	.0	.0	.0					2.0	5.7
NNW	.5	1.4	1.2	.6	.2	.1	.0	.0				3.9	8.1
VARBL													
CALM												15.0	
	10.7	30.1	26.0	14.5	2.7	.8	.1	.0	.0			100.0	6.6

TOTAL NUMBER OF OBSERVATIONS 151392

SOURCE: National Climatic Center, *SSWO (PART C)*.

1210 WS FORM 0.8.5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

SURFACE WINDS

PERIOD SUMMARY BY VELOCITY GROUPS

SOLDOTNA, ALASKA (AVERAGE OF 5 OBSERVATIONS PER DAY) (ANNUAL) PERIOD: March 1962-December 1964

Speed / Dir.		1 - 3 MPH	4 - 15 MPH	16 - 31 MPH	32 - 47 MPH	> 47 MPH	Total No. of Observations %	Total No. of Observations Obs.
N		72	84	10			4.1	166
NNE		42	174	4			5.5	220
NE		104	186	1			7.3	291
ENE		74	118	5			4.9	197
E		300	232	7			13.5	539
ESE		34	46	2			2.0	82
SE		31	41	1			1.8	73
SSE		12	65	3			2.0	80
S		33	98	12			3.6	143
SSW		9	118	14			3.5	141
SW		11	86	3			2.5	100
WSW		14	63	3			2.0	80
W		83	373	2			11.4	458
WNW		18	59	1			1.9	78
NW		20	43				1.6	63
NNW		15	50	1			1.7	66
CALM	1231						30.7	1231
TOTAL	1231	872	1836	69			100.0	4008
PERCENTAGE BY SPEED GROUP:								
	30.7	21.8	45.8	1.7				

SOURCE: National Climatic Center.

PORT GRAHAM: INFORMATIONAL RESOURCES

- Port Graham Salmonid Resource
- Reference to Comments in Drift River Section
- Biological Resources of Port Graham
- Port Graham Vicinity Mammals and Birds
- Surface Winds - Homer

PORT GRAHAM SALMONID RESOURCES

Catch statistics are available for the Port Graham-Kachemak Bay area. Pink salmon are the most abundant salmon with even-year runs being at least double the odd year runs. The catches for 1965-1971 are listed below:

Sockeye	15,900	(11,200 - 26,300)
Pink	123,700	(60,500 - 217,900)
Chum	34,000	(2,500 - 117,300)
Coho	2,800	(500 - 4,700)
King	75	(10 - 175)

There are major pink salmon spawning sites in the Port Graham-Seldovia area. The escapements to these streams has been approximately double the catch, so abundant estimates can be calculated by multiplying the catch by three (for pinks). The run timing is the same as for Kamishak Bay. The pink salmon fishery occurs from June 1 through mid-August. The presence of pink salmon in the bays during the Summer could be critical. There is extensive sport fishing in the area for both salmon and trout. The Anchor River is important for king salmon, steelhead, and Dolly Varden sport fishing.

The Dolly Varden evidently move out of the rivers before the ice melts in the Spring, and it is not known if they stay in the vicinity of Cook Inlet. There is a saltwater sport fishery on Dolly Varden and real census taken during July-August indicates they are present then, in fair numbers, along the shorelines.

SOURCES: Compiled by Larry G. Gilbertson, Consultant to MSNW.

1. International North Pacific Fisheries Commission. Statistical Yearbook (for the years stated).

2. Alaska University, *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U. S. Department of Commerce, COM-73-10337, August 1972.

SEE DRIFT RIVER SECTION FOR GENERAL COOK INLET COMMENTS ABOUT ADDITIONAL FISH AND SHELLFISH.

BIOLOGICAL RESOURCES OF PORT GRAHAM

AREA: Cook Inlet
SUB-AREA: Port Graham
SEASON:
HABITAT: Pelagic Shallows

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Diatoms 1, 2 *Chaetoceros debilis*	Medium	High				High						Dominants in Kachemak Bay
Thalassiosira	Medium	High				High						
Ceratauline Fragilaria	Medium	High				High						
Ditylum brightwellii		High										See Mironov and Lanskae 1968 For Toxidity Information
Dolly Varden *Salvelinus malma*	Medium	Med.	-	Low	Med.	Med.						Caught in Kachemak Bay in Summer
Pacific Halibut *Hippoglossus stenolepis*	High	Low	High	Med.	High	Med.						Winter in Kachemak Bay. In Abundance July to September Sport Fishery May to August.
Pacific Herring *Clupea harengus pallasi*	High (Decreasingly)	High (as Larvae)	High	-	-	High		Spring		Adults	Zooplankton	Most (active spawning) abundant in Kachemak Bay - up to 20,000,000 pounds is harvested - Inshore in Spring and Summer. See USDI No. 4 (1972)

BIOLOGICAL RESOURCES OF PORT GRAHAM (CONT'D.)

AREA: Cook Inlet
SUB-AREA: Port Graham
SEASON:
HABITAT: Pelagic Shallows

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Eulachon *Thaleichthys pacificus*	Medium	High	Low	Low	High	High		May		Spawning Adults		
King Crab[3,4] *Paralithodes camtschatica*	High 100-1000 lbs. Hr.	Low	High	-	Medium	Med.		Feb to May Molt & Copulate		Adults		Highest catches between Kachemak and Kamishak Bays. Commercial Fishery ($1 Million to Fishermen) in Kachemak Bay August to September Potential of 5 + Million Pounds per Year.
King Crab[3,4] *Paralithodes camtschatica*	High	High (When exposed)	-	-	-	High		March to May Eggs Hatch Peak April	45 to 90 Middle and Bottom Zones			Crabs at Kachemak Bay may originate (Summer and Fall) from Kodiak area.

BIOLOGICAL RESOURCES OF PORT GRAHAM (CONT'D.)

AREA: Cook Inlet
SUB-AREA: Port Graham
SEASON:
HABITAT:

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Tanner Crab [1, 5] *Chionoecetes* sp.	High 100 to 1000 lbs/HR	Low	High	Low	Low	Med.		June to July Molt and Breed		Adult		1971 Cook Inlet catch of close to 2 million pounds. 1972 Cook Inlet catch of 4 to 5 million pounds. Fishery peaks May to July.
Tanner Crab *Chionoecetes* sp.	High	High	-	-	-	Med.		April to May Hatch	Pelagic	Larvae		Two to four weeks as pelagic larvae.
Dungeness Crab [3] *Cancer magister*	High	High	High	Med.	High	High		May to June Breeding Eggs laid in Fall hatch in Spring		Adults		Catches in Kachemak Bay June to October - Total Catch 1.5 million pounds in 1963.
Dungeness Crab *Cancer magister*		High	-	-	-	Med. (Fish Food)				Larvae		Migrate into shallow waters in Spring and Summer, deeper waters in Spring and Fall.
Pink Shrimp [6, 3] *Pandalus borealis*	High >1000 Lbs./HR.	Low (High if exposed)	High	-	Low	High		Molt in September				Bound by 5 million pound quota. Peak catches in March, low in January, May and December - generally.
Humpy Shrimp *P. goniurus*	Med. to High	Low (High if exposed)	High	-	Low	High		Lay eggs in October				Concentrate in February, March, April off Yukon Island south of Homer
Coonstripe Shrimp *P. hypsinotus*	Med. to High	Low (High if exposed)	High	-	Low	High		Eggs hatch in May				

BIOLOGICAL RESOURCES OF PORT GRAHAM (CONT'D.)

AREA: Cook Inlet
SUB-AREA: Port Graham
SEASON:
HABITAT: Pelagic and Shelf Waters

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Soft Shrimp *P. platyceras*	Med.	Low (High if exposed)	High	-	Low	High						
Hippolytidae ssp.	High	Low (High if exposed)	Low	-	-	High						
Crangonidae ssp.	High	Low (High if exposed)	Low	-	-	High						

BIOLOGICAL RESOURCES OF PORT GRAHAM (CONT'D.)

AREA: Cook Inlet
SUB-AREA: Port Graham
SEASON:
HABITAT: Pelagic - Shelf Waters

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	IMPORTANCE: ENDANGERED SPECIES	LIFE HISTORY: SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Scallop *Patinopecten caurinus*	Low	Low (High when exposed)	Low	-	-	-		June-July	Deep Water	Adults		Conc. between Augustine Island and Barren Islands

BIOLOGICAL RESOURCES OF PORT GRAHAM (CONT'D.)

AREA Cook Inlet
SUB-AREA Port Graham
SEASON
HABITAT Intertidal - Sand Beaches

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	COMMERCIAL	SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Razor Clam [1] *Siliqua patula*	Medium	High	Low	Low	High	High		June to August		Adult		Conc. between Clark Gulch and Deep Creek - Stariski Creek Areas
Razor Clam *Siliqua patula*	Medium	High	-	-	-	-		Eight-week period		Larvae		

BIOLOGICAL RESOURCES OF PORT GRAHAM (CONT'D.)

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. Alaska University, *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U. S. Department of Commerce, COM-73-10337, August 1972.

2. Knull, J. R. and R. Williamson, *OCEANOGRAPHIC SURVEY OF KACHEMAK BAY, ALASKA*, Three Reports for April, July and October, 1969, U.S.D.I. Bur. Comm. Fish. Manuscript File Reports No. MR-F 60, 70, and 76, 1969.

3. Flagg, L. B., *1971 COOK INLET ANNUAL REPORT, SHELLFISH SECTION*, Alaska Dept. Fish and Game, Commercial Fisheries Division, 1972.

4. Powell, G. C., and R. E. Reynolds, "Movements of Tagged King Crab *(Paralithodes camtscatica tilesius)* in the Kodiak Island, Lower Cook Inlet Region of Alaska, 1954-1963," *ALASKA DEPT. OF FISH AND GAME, INFORM. LEAFL. 55*, 1965.

5. National Marine Fisheries Service, *TANNER CRAB: JOINT PLAN FOR THE FISHERY*, NMFS, 86 pp., 1971.

6. Barr, L., and R. McBride, *SURFACE-TO-BOTTOM POT FISHING FOR PANDALID SHRIMP*, U. S. Fish and Wildlife Service, Spec. Sci. Rept. Fisheries No. 560, 1967.

PORT GRAHAM AND VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1]	Streams Grass Flats	Very few bears in this unit and none near the spill site.
Black Bear[1]	Streams Grass Flats	High densities, many local concentrations, cleanup impact may experience numerous difficulties.
Sheep[2]		Mountain goats not expected to be impacted. Possible occurrence of the animals in beach areas during periods of major snow buildup.
Wolves and Wolverines[1]	Willow Flats Beaches	Estimated 20 to 50 wolves in all of Unit 15 and increasing. Wolverine population low, major impact is possible food loss, fur animal (commercial).
Moose[1]	Willow Flats	Moose range does not extend to likely impact areas except at Kachemak Bay. Remainder of unit considered best moose range in the world with density of 15 per square mile. Total population is 15,000 to 17,000.
Aquatic Furbearers[2]	Beaches Estuaries Marshes	Species: River otter, beaver, muskrats, mink. Main impact losses of food. Possible mortality of young during spring denning.
Small Mammals[1]	Marshes and Willow Flats	Main impact expected on the species habitat.
Harbor Seal[1]	Inshore Areas Beaches	No population estimate. High local concentrations, particularly in Nuka Bay, Nuka Passage and Port Dick.
Northern Fur Seal[2]	Inshore Areas Beaches	Transient animals only.
Sea Lion[1]	Rocky Caves Rivers Beaches	Population as follows: Flat Island - 300, Cape Elizabeth - 30, Nagahut Rocks - 50, East Chugach Island - 20, Gore Point - 220. Formerly harvested now protected by Marine Mammal Protection Act.
Sea Otter	Nearshore Seas	Formerly closed as endangered. Recolonizing area and increasing. Seldom found north of English Bay. Could be heavily impacted by oil spill. Common in Port Dick, Port Chatam and Chugach Bay.
Beluga Whales	Open Sea	Few in area, estimated 100 to 300 in whole of Cook Inlet area.
Ducks	Open Sea Mud Flats Estuaries Marshes	USFS estimate 12 breeding ducks per square mile of suitable habitat area. Major wintering area - particularly Kachemak Bay. Major migration zone. Commercial guiding possible. Potential exists for long-term habitat damage.

PORT GRAHAM AND VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Geese[2]	Mud Flats Estuaries Potholes	Possible long term habitat damage.
Swans[1]	Mud Flats Estuaries Ponds	Peninsula a major breeding area. Some overwintering populations in mild Winters.
Seabirds[1]	Near Seas Beaches	Seabird colonies of mixed species as follows: Elizabeth Island, Pearl Island, East Chugach Island, Windy and Rocky Bays, Port Dick and Nuka Point.
Shorebirds[2]	Beaches Mud Flats Estuaries	Possible impact on food organisms.
Upland Game Birds[2]		
Raptors[2]	Beaches Mud Flats Estuaries	Possible impact on foods, mainly spawning salmon.

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

SURFACE WIND DATA - HOMER, ALASKA

1139 D ? Observations Daily.

PERIOD SUMMARY BY COMBINED-VELOCITY GROUPS

STATION HOMER, ALASKA ~~MONTH~~ ANNUAL PERIOD FEB. 1939 - APR. 1941

DIR. / MPH	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOT. OBS.	%
4-15	25	18	168	190	130	103	52	31	60	13	75	71	134	48	15	8	1141	70
16-31	4	3	2	11	4	15	4	7	2		11	23	33	13	2	2	136	8
32-47											2	2	1	3			8	1
OVER 47																		
CALM																	340	21
TOT. OBS.	29	21	170	201	134	118	56	38	62	13	88	96	168	64	17	10	1625	
%	2	1	11	12	8	7	3	2	4	1	5	6	11	4	1	1	CALM 21	100

SOURCE: National Climatic Center.

KAMISHAK BAY: INFORMATIONAL RESOURCES

- Kamishak Bay Salmonid Resources
- Reference to Comments in Drift River Section
- Biological Resources of Kamishak Bay
- Kamishak Bay Vicinity Mammals and Birds

KAMISHAK BAY SALMONID RESOURCES

The commercial catches in Kamishak Bay are low. Seven-year averages (1965-1971) are given below:

	AVERAGE	RANGE
Sockeye	7,239	(21 - 38,400)
Pink	52,403	(2,945 - 208,325)
Chum	37,500	(3,175 - 95,900)
Coho	159	(74 - 300)

The total runs would be something greater but since there is little information on fishing effort, an estimate is difficult. A conservative estimate of abundance would be twice the catch.

Timing for the runs would be mid May to late August for the adults and early May to late August for the juveniles. Pink and chum salmon juveniles are of special interest during the summer months (especially early Summer), as they are found in the shallow waters along shorelines when they feed before moving offshore toward the Gulf of Alaska.

Spawning in the area is minimal (although the data is scant). There are sizable chum salmon runs into the McNiel River.

There are some anadromous trouts in the Inlet (Dolly Varden, steelhead), but there distribution is unknown. There are probably some in Kamishak Bay, but there is no data to make an abundance estimate.

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. International North Pacific Fisheries Commission. Statistical Yearbook (for the years stated).

2. Alaska University, *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U. S. Department of Commerce, COM-73-10337, August 1972.

SEE DRIFT RIVER SECTION FOR GENERAL COOK INLET COMMENTS ABOUT ADDITIONAL FISH AND SHELLFISH

BIOLOGICAL RESOURCES OF KAMISHAK BAY

AREA: Cook Inlet
SUB-AREA: Kamishak Bay
SEASON:
HABITAT: Nearshore (Shelf) Waters

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
King Crab[1] *Paralithodes camtschatica*	Medium - low	Low	High	Low?	Low?	Med.		February - May - Molt and Copulate		Adults		
King Crab[1] *Paralithodes camtschatica*								March - May Hatch Peak in April	45-90m in bottom and mid-depths	Larvae		
Tanner Crab[2] *Chionoectes* Sp.	High	Low	High	Low?	Low?	Med.		June - July Molt and Breed		Adult		Catch high in Kamishak District. Concentration between Augustine and Barren Islands
Tanner Crab[2] *Chionoectes* Sp.	High?	High	-	-	-	Med.		April - May Hatch	Pelagic	Larvae		Two to four weeks as pelagic larvae Fisher peaks May - June
Dungeness Crab *Cancer magister*	Med. - Low	High	High	Med.?	High? Med.	High		May - June		Adults		Not so abundant. Not heavily fished commercially.
Dungeness Crab *Cancer magister*		High	-	-	-	Medium (Fish Food)		Breeding Eggs Laid in Fall Hatch in Spring		Larvae		
Pink Shrimp[3, 4] *Pandalus borealis*	Low	Low	Low			High		Molt in September				General Characteristics.
Humpy Shrimp *P. goniurus*	Low	Low	Low			High		Lay Eggs in October				

BIOLOGICAL RESOURCES OF KAMISHAK BAY (CONT'D.)

AREA: Cook Inlet
SUB-AREA: Kamishak Bay
SEASON:
HABITAT: Nearshore (Shelf) Waters

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Coonstripe Shrimp *P. hypsinotus*	Low	Low	Low			High		Molt in Sept. Lay Eggs in October. Eggs Hatch in May				General Characteristics
Spot Shrimp *P. platyceros*	Low	Low	Low			High						
Sidestripe Shrimp *Pandalopsis dispar*	Low	Low	Low			High						
Hippolytidae ssp.	Low	Low	Low			High						
Crangonidae ssp.	Low	Low	Low			High						
Scallop[1] *Patinopecten caurinus*	Low	Low (High when exposed)	Low	-	-			June - July	Deep Water			Concentrated between Augustine Island and Barren Islands to 600 lbs/hr.

BIOLOGICAL RESOURCES OF KAMISHAK BAY (CONT'D.)

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. Alaska University, *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U. S. Department of Commerce, COM-73-10337, August 1972.

2. National Marine Fisheries Service, *TANNER CRAB: JOINT PLAN FOR THE FISHERY*, NMFS, 86 pp., 1971.

3. Barr, L., and R. McBride, *SURFACE-TO-BOTTOM POT FISHING FOR PANDALID SHRIMP*, U. S. Fish and Wildlife Service, Spec. Sci. Rept. Fisheries No. 560, 1967.

4. Flagg, L. B., *1971 COOK INLET ANNUAL REPORT, SHELLFISH SECTION*, Alaska Dept. of Fish and Game, Commercial Fisheries Division, 1972.

KAMISHAK BAY VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1]	Grass Flats Estuaries	One of State's best brown bear areas. McNeil River perhaps world's most important area for photography of bears. Local population perhaps (500) Unit 2,000 bears.
Black Bear[1, 2]	Grass Flats Estuaries	Population low; extreme edge of range. No concentrations in area.
Moose[1, 2]	Willow Flats	Low but increasing population. Possible disturbance by shore cleanup. Possible loss of calves on willow flats.
Caribou[1, 2]	Muskeg	Extreme edge of range on Alaska Peninsula.
Wolves and Wolverines[1]	None	Population low. Few wolves taken. $\bar{x}$ 36 wolverines harvested in Unit 9 per year.
Aquatic Furbearers[2]	Beaches Estuaries	Land otter, mink, beaver, muskrats. All possibly subject to oil spread to onshore areas.
Small Mammals	Low Vegetative Areas	Some possible impact if oil spreads inshore.
Sea Otter[1]	Inshore Areas	Population increasing from former near extirpation. Augustine Island and Paule Bay 1,000 and increasing.
Harbor Seal[1]	Nearshore Areas Estuaries Flats	Population size unknown. Local concentrations.
Northern Fur Seal[1]		Transients
Sea Lion[1]	Rocky Caves	Formerly harvested. Rookery on Augustine Island protected under Marine Mammal Protection Act.
Beluga Whale[2]	Open Sea	
Ducks[1]	Inshore Sea Mud Flats Estuaries	USFS Estimate: 32 breeders per square mile - mixed species Unit 9. However, this area certainly below this abundance. Possible permanent damage to habitat. Legislative protected area.
Geese and Brant[1]	Nearshore Areas Mud Flats Estuaries	Goose nesting. Important and heavy goose and brant migration area.
Swans[1]	Nearshore Areas Mud Flats Estuaries	Trumpeters breed in Tuxedni Bay. Survey showed two whistling swans per square mile.

KAMISHAK BAY VICINITY MAMMALS AND BIRDS

ORGANISM GROUPS (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Shorebirds[1]	Mud Flats Beaches	Heavy Fall - Spring migration. Includes heave migration of sandhill cranes.
Seabirds[1]	Nearshore Waters	Mixed colony on Glacier Spit, Chinitna Bay. Mixed colony on Augustine Island.
Upland Game Birds[2]		
Raptors[2]		

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

UNIMAK PASS: INFORMATIONAL RESOURCES

- Unimak Pass Salminid Resources
- Fish and Shellfish Important at Unimak Pass
- Biological Resources of Unimak Pass
- Unimak Pass Vicinity Mammals and Birds
- Gulf of Alaska - Surface Winds
- Surface Winds - Driftwood Bay

UNIMAK PASS SALMONID RESOURCES

Unimak Pass is important from two aspects: (1) there are local fisheries and salmon populations; (2) it is in the migratory route of part of the Bristol Bay salmon runs. The percent of the Bristol Bay run that passes through Unimak Pass is unknown but at least in some years it is an important route for stocks coming out of the Gulf of Alaska and the Northwest Pacific Ocean. The timing would be approximately June 1 to August 31, with the peak most likely around June 5 to 10.

The salmon catches of the local fisheries are small but most of the fishermen are local inhabitants (False Pass) and so the take is important to the local economy. The catches for the Unimak area have, in recent years, averaged approximately:

Sockeye	400,000
Coho	20,000
Pink	70,000
Chum	320,000

The fisheries occur during June and July.

For abundance estimates I think you could say the number of Bristol Bay fish moving through the Pass would be potentially several million in some years. For the local stocks a reasonable estimate would be twice the catch. In the case of chum salmon it would probably be much greater than twice the catch since only 25 percent of those caught are from local stocks. The abundance of chums is probably in the millions and some are of Asian origin (Kamchatka, Anadys rivers). There is also some evidence that Asian pink salmon are in the Unimak Pass area.

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. Royce, W. F., L. S. Smith and A. C. Hartt, "Models of Oceanic Migrations of Pacific Salmon and Comments on Guidance Mechanisms," U. S. Fish and Wildlife Service, *FISHERY BULLETIN*, 66(3):441-442, 1968.

2. Hartt, A. C., "Movement of Salmon in the North Pacific Ocean and Bearing Sea as Determined by Tagging, 1956-1958," *INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION, BULLETIN 6*, 1962.

3. Bureau of Sport Fisheries and Wildlife and U. S. Department of the Interior, *ENVIRONMENTAL STATEMENT, PROPOSED UNIMAK WILDERNESS, ALEUTIAN ISLANDS NATIONAL WILDLIFE REFUGE, ALASKA*, DES 72-114, Final, 1972.

FISH AND SHELLFISH IMPORTANT AT UNIMAK PASS

Halibut
Pollock
Flathead Sole
Pacific Ocean Perch
Pacific Cod
Black Cod
Cottids
King Crab
Tanner Crab
Shrimps

HALIBUT

Relatively unimportant to commercial fishing. A few fish have been taken from along the Aleutian Islands each year. The shallow areas of both the Bering Sea side and the Pacific Ocean side of Unimak Island are extremely important to young halibut.[2,3] Young of the year were taken with beach seines along the Pacific side of the Alaska Peninsula in May.[4]

POLLOCK

No domestic fishery yet but extremely important for foreign trawlers just north of Unimak Pass.

KING CRAB AND TANNER CRAB

Important domestic fishing on both shores of Unimak Island and along the Aleutian Islands.

SHRIMP

Very important domestic fishery in bays of the Aleutian Islands.

PACIFIC OCEAN PERCH

Pacific Ocean Perch fished by foreign fleets in deep water just south of Unimak Pass.

FLOUNDERS

Several species of flounders are found in the shallow water of this area. Rock sole are probably most important flounder in shallow bays. Yellowfin, butter and flathead sole are also present.

FISH AND SHELLFISH IMPORTANT AT UNIMAK PASS (CONT'D.)

SOURCES:

1. Best, E. A., International Pacific Halibut Commission, personal communication.

2. Best, E. A., International Pacific Halibut Commission Technical Report 12:63 p., 1974.

3. Best, E. A., International Pacific Halibut Commission Technical Report 11:32 p., 1974.

4. Thompson, W. F., and R. Van Cleve, *LIFE HISTORY OF THE PACIFIC HALIBUT, (2) DISTRIBUTION AND EARLY LIFE HISTORY,* Report of the International Fisheries Commission No. 9, Seattle, Wash., 182 pp., 1936.

BIOLOGICAL RESOURCES OF UNIMAK PASS

AREA: Unimak Pass
SUB-AREA: North of Unimak Island and Bechevin Bay
SEASON:
HABITAT: Mud-Sand Sediments - Deep

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	IMPORTANCE: ENDANGERED SPECIES	LIFE HISTORY: SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
GENTERAL BENTHIC[1-5] Fauna Polychaetes Mollusks Echinoderms	Sparse <10 g/m^2	Low	-	-	-	Medium (Food Organisms for Fishes)						Population density increases on Bay's periphery Utilized by: Yellowfin Sole, Rock Sole, Alaska Plaice, Flathead Sole
Ophiura sarsi	25g/m^2					High (King Crab Food)			Shallow Shelf			
Polychaetes and Bivalve Mollusks[6]	57g/m^2		-	-	-	High (King Crab Food)						
King Crab[7-10] *Paralithodes camtschatica*	High	High ? (When exposed)	High	-	Low			April to June Eggs hatch Females molt and breed	Shallows	Adults	Brittlestars and other Benthic Organisms	More males than females Concentrated in area in Winter. Migrate to shallows <100 m to breed in Spring. Immatures spend Summer inshore. Feeding ground of importance.
King Crab[7-10] *Paralithodes camtschatica*		High						April to June Males molt January-December Females carry eggs May-July Planktonic Larvae	Pelagic Larvae			

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA: Unimak Pass
SUB-AREA: North of Unimak Island and Bechevin Bay
SEASON:
HABITAT: Mud - Sand Sediments - Deep

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	LIFE HISTORY: SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Tanner Crab[11-18] *Chionoecetes opilio*	Medium	High (When exposed)	High	-	Low			January-April Breed, eggs hatch	50-90m	Adults		
Tanner Crab[11-18] *Chionoecetes opilio*		High						January-June Planktonic for 63 to 66 days		Larvae		
Dungeness Crab[13] *Cancer magister*	Medium	High?	Low - None	Low	Low	?		April-May Mate		Adults		Mate in Shallows.
Dungeness Crab *Cancer magister*									Pelagic	Larvae		Planktonic for 111 days

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA Unimak Pass
SUB-AREA Northwest Tip of Unimak
SEASON
HABITAT Rocky Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	LIFE HISTORY: SPAWNING ERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Pink Shrimp[1,4,14] *Pandalus borealis*	No Comm. Quant.	Low ?	-	-	-	High (Fish Food)		August-Sept. Spawning	90 m or >	Adults		Large diel migration. (Night Impact?)
Pink Shrimp *Pandalus borealis*	No Comm. Quant.	High ?				High (Fish Food)		August-April Females carry Eggs; February-May Hatch; February-July Free-swimming; May-July Settle to Bottom	Pelagic	Larvae		In Autumn migrate into 20 m to breed.
Humpback Shrimp[1,4,14] *P. goniurus*	No Comm. Quan.	Medium				High (Fish Food)			20-30 m first 2 years then deeper	Adults		In Autumn migrate into 20 m to breed.
Spotted Shrimp[1,4,14] *P. platyceros*									30-55 m	Adults		In Autumn migrate into 20 m to breed.
Sidestripe Shrimp[1,4,14] *Pandalopsis dispar*	No Comm. Quan.	Low ?				High (Fish Food)			90 m or >	Adults		In Autumn migrate into 20 m to breed.
Weathervane Scallops[15,16] *Patinopecten caurinus*	Low Abundance comm.	Low ?	Low	-	-	Medium (Other Food)?		June	Bottom	Adults		

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA: Unimak Pass
SUB-AREA: Northwest Tip of Unimak
SEASON:
HABITAT: Rocky Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEP H RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Walleye Pollock [17,18] *Theragra chalcogramma*	In Excess of 1,800 kg/Hr.	Low	High	-	-	High		February-May	Conc. 45-110m	Adults	Zooplankton and small fish	$500 million annual worth to U. S.
Walleye Pollock *Theragra chalcogramma*		High	-	-	-	Medium		February-June		Eggs and Larvae		Early Summer catches > 90 kg/Hr. in 45 to 80 m depths. Concentrations in upper 10 m. Note: Large concentration of spawners in this area.
Pacific Cod [17] *Gadus macrocephalus*	Max. 1,300 kg/Hr.	Low	High	Low	-	High		January-April	65-80m	Adults	Bottom Crustaceans	Potential yield of 17 to 23 metric tons. Spawn in waters 100-250 m. Demersal eggs.
Sablefish [17] *Anoplopoma fimbria*	Low	Low	Med.						365 to 430 m		Small Fish Worms and Crustaceans	Potential yield 13.6 to 22.7 thousand metric tons. Closer to surface furing daylight.
Pacific Ocean Perch [19,20] *Sebastes alutus*	Low-Med.	Low	High	-	-	Med.		September-Oct. Copulation	145 to 460 m	Adults	Plantonic Crustaceans	Potential yield 22.7 to 45.4 thousand metric tons for all Bering. 20 to 60 m above rocky bottoms.
Pacific Ocean Perch *Sebastes alutus*								March-April Larvae expelled at 360 to 420 m	20 to 80 m	Larvae		Juveniles found in colder, shallower waters. Larvae pelagic southeast of Pribilofs. Large concentration of Winter and Spring schools of rockfish. Associated with Gyres.

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA: Unimak Pass
SUB-AREA: Northwest Tip of Unimak
SEASON:
HABITAT: Rocky Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Weathervane Scallops *Patinopectin caurinus* 15,16	Low Abundance comm.	Low	-	-	-			June	Bottom	Eggs		
Weathervane Scallops *Patinopectin caurinus*	Low Abundance Comm.	High ?	-	-	-	Medium		June-July Plan.	Plantonic	Larvae		

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA: Unimak Pass
SUB-AREA: Northwest Tip - Unimak
SEASON:
HABITAT: Gravel (Shelf) Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Rock Sole[1,21,22] *Lepidopsetta bilineata*	High 90-270 kg/Hr.	Low	High (Poten.)	-	-	High		February-April-May	Summer 40-120m Winter 60-160m	Adults	Polychaetes Mollusks Crustaceans (Shrimps)	Estimated potential annual yield 90.7 - 136,000 metric tons. Associated with yellowfin sole. Migrates into shallow in Summer; Disbursed.
Yellowfin Sole[23] *Limanda aspera*	High	Low	High	-	-	High		June-August	Summer 40-120m Winter 60-180m	Adults	Shrimp Bivalve Mollusks Ophiuroids Amphipods	Migrate from deep water in Winter to shelf in Summer. Large Winter concentration near Unimak Island along 3.2-4.3 C Water mass.
Starry Flounder[23] *Platichthys stelatus*	Low	Low	-	-	-	Low		May-June	Winter on slope Summers on shallow shelf	Adults	Polychaetes Shrimp Mollusks	Two forms (coastal and marine)
Arrowtooth Flounder[23] *Atheresthes stomias*	Med.-High 90-270 kg/Hr.	Low	Low	-	-	Low		April-May?	?	Adults	Shrimps Fish - Herring Sandlance	Estimated 18,000 to 36,000 metric ton yield.
Pacific Halibut[24-26] *Hippoglossus stenolepis*	High 100-200 kg/Hr.	Low	High	Low	Low	High?		November-February	>80 m	Adults	Fish: Yellowfin Sole Pollock Sandlance	In area primarily January to April. Note: Area considered as important halibut rearing area.
Pacific Halibut[24-26] *Hippoglossus stenolepis*	-	High (if exposed)	-	-	-	High		6 to 7 mo. period	Pelagic midwater to surface	Eggs/Larvae		Larvae often carried into shallows.

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA Unimak Pass
SUB-AREA Northwest Tip of Unimak
SEASON
HABITAT Gravel (Shelf) Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Aleutian Skate[23,22] *Raja aleutica*	Low	Low	-	-	-	Low						
Longhead Dab[26] *Limanda proboscidea*	Low	Low	-	-	-	Low		July-August	Winter in 100m Summer 40-100m	Adults		
Alaska Plaice[21] *Pleuronectes quadrituberculatus*	Low	Low	-	-	-	Low		May-June	Winter 100-200m Summer 30-100m	Adults		Rare on slope in Winter. Moves into shallows in Summer but does not form concentration.

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA: Unimak Pass
SUB-AREA:
SEASON:
HABITAT: Rocky - Kelp Nearshore Subtidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Kelp Greenling[25,26,28] *Hexagrammos decagrammus*	Medium	Low (except during spawning)	-	-	-	Medium						Many provide sea otter, seal and sea lion food items
Whitespotted Greenling *H. stelleri*	Low	Low (except during spawning)	-	-	-							Many provide sea otter, seal and sea lion food items.
Rock Greenling *H. lagocephalus*	High	Low (except during spawning)	-	-	-	Medium-High						Many provide sea otter, seal and sea lion food items.
Red Irish Lord *Hemilepidotus hemilepidotus*	Medium	Low	-	-	-	Low						Many provide sea otter, seal and sea lion food items.
Yellowfish Lord *E. jordani*	Low	Low	-	-	-	Low						Many provide sea otter, seal and sea lion food items.
General Sculpins:	Low	Low	-	-	-	Low						
Triglops macellus	Low	Low	-	-	-	Low						Many provide sea otter, seal and sea lion food items.
T. forficata	Low	Low	-	-	-	Low						
Clynocottus embryum	Low	Low	-	-	-	Low						Many provide sea otter, seal and sea lion food items.
C. acuticeps	Low	Low	-	-	-	Low						
Myoxocephalus polyacanthocephalus	Low	Low	-	-	-	Low						Many provide sea otter, seal and sea lion food items.

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA Unimak Pass
SUB-AREA
SEASON
HABITAT Rocky - Kelp Nearshore Subtidal

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Liparids *Lethotremus muticus*	Low	Medium	-	-	-	Low						
Liparis callyodon	Low	Medium	-	-	-	Low						
Aptocyclus ventricosus	Medium	High (especially during spawning)	-	-	-	Med.						Preferred otter food.
Three-spined Stickleback *Gasterosteus aculeatus*	Low	Low	-	-	-	Low-Med.						
Nine-spined Stickleback *Pungitius pungitius*	Low	Low	-	-	-	Low-Med.						
Searcher *Bathymaster signatus*	Low	Low	-	-	-	Low						
Langbarn[26,27] *Leptoclinus maculatus*	Low	Low (except during spawning)	-	-	-	Low-0						
Crescent Gunnel *Pholis laeta*	Low	Low (except during Summer)	-	-	-	Low 0						

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA: Unimak Pass
SUB-AREA: Cold Bay
SEASON: Summer
HABITAT: Sandy Beaches and Lagood Mud Flats

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Razor Clams 1,26,28 *Siliqua patula*	High	High	-	Low	Low			July	Inter-tidal	Larvae July-Nov. Setting Aug-Nov.		
Cockle *Clinocardium nuttallii*			-	Med.	Med.				Inter-tidal			
Littleneck Clams *Protothaca staminea*			-	Med.	High				Inter-tidal			
Butter Clams			-	Med.	High				Inter-tidal			

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA: Unimak Pass
SUB-AREA: Ocean Waters N.
SEASON: Summer
HABITAT: Pelagic Ocean

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Zooplankton Biomass[30]	200-500 mg/m^3	High?				High						Declines in early Fall when seaward migrating smolts enter outer bay.
Larval Bivalves[31] and Euphausids in Dev. Stages						High				Early		
Pacific Sandlance[31,32] *Ammodytes hexapterus*									Pelagic	Larvae and Young Stages		Sockeye Food
Euphausiid Eggs[31,32] and Larval Stages										Early All Stages		Sockeye Food
Copepods[31,32]										Adult		Sockeye Food
Cladocera[31] *Podon* sp.										Adult		
Pteropods[31]												
Decapod												
Pacific Herring[22,23] *Clupea harengus pallasi*	Med.	High?	Med.-High	-	-	High		April-May	Pelagic to 70 m	Adults	Zooplankton Euphasiids	Abundant in September-October.
Atka Mackerel[34] *Pleurogrammus monopterygius*	High	Low	-	-	-	High		July	Pelagic	Adults	Large Zooplankton Mysids	Concentrate around Pass for spawning.

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

AREA: Unimak Pass
SUB-AREA: Ocean Waters N.
SEASON: Summer
HABITAT: Pelagic Ocean

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Capelin[27,28,35] *Mallotus villosus*	Med.-High	High	-	-	-	high		September-October	Pelagic	Adults		Spawn on gravel beaches in area.
Dolly Varden[26] *Salvelinus malma*	Med.	Low - Medium	-	-	Low	Med.		Fall	Pelagic	Adults		Anadromous.

BIOLOGICAL RESOURCES OF UNIMAK PASS (CONT'D.)

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. Artic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, prepared for the Department of the Army, Alaska District, Corps of Engineers, February 1974.

2. Semenov, V. N., "Quantitative Distribution of Benthos on the Shelf of the Southeastern Bering Sea (Bristol Bay, Alaska Peninsula Coast, and Unimak Island)," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART III*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

3. Neiman, A. A., "Quantitative Distribution of Benthos on the Shelf and Upper Continental Slope in the Eastern Part of the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART I*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1963.

4. Ivanov, B. G., "Quantitative Distribution of Enchinodermata on the Shelf of the Eastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

5. Neiman, A. A., "Age of Bivalve Mollusks and the Utilization of Benthos by Flatfishes in the Southeastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART III*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

6. Lus, V. Y., "Quantitative Distribution of Benthos on the Continental Slope of the Eastern Part of the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

7. Korolev, N. G., "The Biology and Commercial Exploitation of the King Crab, *Paralithode camtschatica* (Tilesius), in the Southeastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

8. Gray, G. W. Jr., and G. C. Powell, "Sex Ratios and Distribution of Spawning King Crabs in Alitak Bay, Kodiak Island, Alaska (Decapoda, Amonura, Lithodidae)," *CRUSTACEANA*, 10(3):303-309, 1966.

9. Rodin, V. E., "Some Data on the Distribution of King Crab, *Paralithode camtschatica* (Tilesius), in the Southeastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

10. Chebanov, S. M., "Biology of the King Crab, *Paralithode camtschatica* Tilesius, in Bristol Bay," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART IV*, P. A. Moiseev, ed., Israel Program for Scientific Translation, 1965.

11. Hayes, E., and C. Lehman, eds., "Minutes of the Second Alaska Shellfish Conference," *ALASKA DEPT. OF FISH AND GAME INFORM. LEAFL. 135*, 1969.

12. Watson, J., "Maturity, Mating, and Egg-laying in the Spider Crab *Chinocetes opilio*," *J. FISH. RES. BD. CANADA*, 27:1607-1616, 1970.

13. Poole, R. L., "A Description of Laboratory-Reared Zoea of *Cancer magister* Dana and Megalopae Taken under Natural Conditions (Decapoda, Brachyura)," *CRUSTACEANA*, 11(1):83-97, 1966.

14. Barr, L., and R. McBride, *SURFACE-TO-BOTTOM POT FISHING FOR PARDALID SHRIMP*, U.S.D.I., Fish and Wildl. Service Spec. Sci. Rept. No. 560, 1967.

15. Hennick, D. P., "Reproductive Cycle, Size at Maturity, and Sexual Composition of Commercially Harvested Weathervane Scallops, *Patinopectan caurinus*, in Alaska," *J. FISH. RES. BD. CANADA*, 27:2112-2119, 1970.

16. Hennick, D. P., *SEA SCALLOPS, PATINOPECTIN CAURINUS, INVESTIGATIONS IN ALASKA*, Commercial Fisheries Research and Development Act Completion Report, Alaska Dept. of Fish and Game, 1973.

17. Faculty of Fisheries - several reports 1964-1967, the Osharu Maru Cruises 4, 9, 14, 19. In: *DATA RECORD OF OCEANOGRAPHIC OBSERVATIONS AND EXPLORATORY FISHING, NOS. 8, 9, 10 and 11.* Hokkaido University (from Source No. 1).

18. Serobaba, I. I., "Distribution of Walleye Pollock, *Theragia chalcogramima* (Pallas), in the Eastern Bering Sea and Prospects of Its Fishery," *SOVIET FISHERY INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

19. Paraketsov, I. A., "On the Biology of *Sebastodes alutus* of the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART I*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1963.

20. Lisovenko, L. A., "Distribution of the Larvae of Rockfish (*Sebastodes alutus* Gilbert) in the Gulf of Alaska," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART III*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

21. Fadeiev, N. S., "Comparative Outline of the Biology of Flatfishes in the Southeastern Part of the Bering Sea and Condition of Their Resources," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART IV*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1965.

22. Shubnikov, D. A., and L. A. Lisovenko, "Data on the Biology of Rock Sole of the Southeastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

23. Skalkin, V. A., "Diet of the Flatfishes in the Southeastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART I*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1963.

24. Novikov, N. P., "Basic Elements of the Biology of the Pacific Halibut, *Hippoglossus hippoglossus stenolepis* Schmidt, in the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

25. Shuntov, V. P., "Distribution of the Greenland Halibut and Arrow-toothed Halibuts in the North Pacific," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART IV*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1965.

26. Bureau of Sport Fisheries and Wildlife and U. S. Department of the Interior, *ENVIRONMENTAL STATEMENT, PROPOSED UNIMAK WILDERNESS, ALEUTIAN ISLANDS NATIONAL WILDLIFE REFUGE, ALASKA*, DES 72-114, Final.

27. U. S. Department of the Interior, *UNIMAK ISLAND WILDERNESS STUDY, ALEUTIAN ISLANDS NATIONAL WILDLIFE REFUGE, THIRD JUDICIAL DISTRICT, ALASKA*, Wilderness Study Report, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife.

28. Wilimovsky, N. J., Inshore Fish Fauna of the Aleutian Archipelago, Proc. 14th Alaska Sci. Conf., 1963.

29. Bricker, Marlin, Alaska Department of Fish and Game, Cold Bay, Personal Communication, (from Source No. 1).

30. Meshcheryakova, I. M., "The Quantitative Distribution of Plankton in the Southeastern Bering Sea in the Summers of 1958 and 1959," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

31. Straty, R. R., "Ecology and Behavior of Juvenile Sockeye Salmon (*Oncorhynchus nerka*) in Bristol Bay and the Eastern Bering Sea, Chapter 14," *OCEANOGRAPHY OF THE BERING SEA WITH EMPHASIS ON RENEWABLE RESOURCES*, D. W. Hood and E. J. Kelly, eds., Univ. of Alaska, Institute of Marine Science, Occas. Pub. No. 2, 1974.

32. Meshcheryakova, I. M., "The Quantitative Distribution of Plankton in the Southeastern Bering Sea in the Summers of 1958 and 1959," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

33. Musienko, L. N., "Reproduction and Development of Bering Sea Fishes," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

34. Rass, T. S., "Deep Sea Fish of Far Eastern Seas of the U.S.S.R.," *ZOOL. ZH.*, 33:1312-1324, Israel Program for Scientific Translations, 1954.

35. Hart, J. L., "Pacific Fishes of Canada," *FISH RES. BD. CANADA, BULLETIN 180*, 1973.

UNIMAK PASS VICINITY - MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[2]	Beaches Grass Flats	Little known about brown bear stocks on Unimak Island. Essentially virgin. Fifteen harvested in 1964. Population believed quite substantial.
Caribou[1, 2]	Low Tundra Grass Flats	Part of peninsula herd with suspected interchanges. Estimate 3,000 on island and building. Emigration expected if overpopulation problems manifest themselves.
Wolves and Wolverines[1, 2]	Beaches	Both believed present in low numbers. A greater population possible due to large available food stores.
Harbor Seal[1, 2] Northern Fur Seal[2]	Beaches Nearshore Seas	Quite abundant throughout area. No harvest even before Marine Mammal Protection Act.
Sea Otter[1, 2]	Beach Coves Nearshore Seas	Area formerly supported a large population. Exterminated but now recolonizing. Population suffered high mortality due to extreme ice conditions in 1971 and 1972. Current population estimates for north Unimak Island and Alaska Peninsula 8,000 to 10,000 and increasing. Species believed highly vulnerable to oil spills.
Sea Lion[1]	Rocky Coves and Beaches	Unit 10 (Aleutian Islands) contains more sea lions than any other game unit. No good estimates. Figures below based on maximal counts but incomplete counts. Populations believed at carrying capacity: Akutan Island north Head) 715, Akun Island (Akun Head) 2,000, Akun Island (Billings Head) 100, Tanginak Island 600, Tegolda Island (west end) 10, Tegolda Island (east end) 750, Aiktok Island 600, Unimak Island, Cape Sarichef 200, Oksenof Point 4,000.
Whales[1]	Open Sea	Harbor and Dall porpoises, killer whales, Pacific pilot whales, Baird's beaked whale and Cuvier's beaked whale normal in area. First three very common in coast waters. Last species relatively uncommon. Male sperm whales occasionally present as migrants. Baleen whales include finback, humpback and minke. Possibility of the rare blue, sei and bowhead (considered endangered forms). Gray whales pass in Winter migration.
Ducks[1]	Open Sea Beaches Grass Flats	Very little population information available. The area is a major migration zone for birds passing both to Asia and to the Americas; Also a major wintering area for sea ducks.

UNIMAK PASS VICINITY - MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Geese[1]	Open Sea Beaches Grass Flats	Major migration population. Also over 100,000 breeding emporer geese known to winter on the Aleutions. Many migrated through the Pass area. Also Asia migrants.
Swans[2]		Major breeding population of whistling swans.
Seabirds[1]	Open Seas Beaches Estuaries	Literally hundred thousands. Little firm population data available. Unimak colonies identified as follows: Kaligagan Island, Cassin's Auklet and Parakeet Auklet, Akutan Island: tufted puffins, Unimak Island: double-crested cormorants, black-legged kittiwake, Aleutian tern (rare).
Shorebirds[2]		
Upland Game Birds[2]		
Raptors[2]		Probable breeding of bald eagles.

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

GULF OF ALASKA II - SURFACE WINDS

Station	Winter Prevailing Direction	Winter Mean Speed (mph)	Summer Prevailing Direction	Summer Mean Speed (mph)	Fastest Mile Direction	Fastest Mile Speed (mph)	2nd Fastest Mile Direction	2nd Fastest Mile Speed (mph)
Afognak	NE; SW		NE; SW					
Kodiak	NW	10.5	E; NW	7		*		*
Chirikof Island	S; SE; SW		W; SW; NW		N	63	NE	57
Chignik	NW; W; SE		SE; W; SW					
Scotch Cap	NW; W; SE		W; SE					
Chernofski	SE; SW; NW		SE; NW					
Unimak								
Nikolski	E; SE; W	17	E; NW	18	W; NW	>65	Several	>63

*Peak gusts of 97 and 99 mph have been observed.

SOURCE: Swift, W. H., R. E. Brown, L. V. Kinnel, M. M. Orgel, P. L. Petersen, W. W. Waddell, *GEOGRAPHICAL ANALYSIS OF OIL SPILL POTENTIAL ASSOCIATED WITH ALASKAN OIL PRODUCTION AND TRANSPORTATION SYSTEMS*, Pacific Northwest Laboratory, Division of Memorial Institute to the United States Coast Guard, February 1974, Final Report No. CG-D-79-74.

DATA PROCESSING DIVISION
ETAC/USAF
AIR WEATHER SERVICE/MAC

PERCENTAGE FREQUENCY OF WIND
DIRECTION AND SPEED
(FROM HOURLY OBSERVATIONS)

SURFACE WINDS

25515 STATION — DRIFTWOOD BAY ALASKA STATION NAME — 71-69 YEARS — ALL MONTH

ALL WEATH CLASS — ALL HOURS (L.S.T.)

CONDITION

SPEED (KNTS) DIR.	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥ 56	%	MEAN WIND SPEED
N	.2	2.4	3.6	1.2	.7	.1	.0	.0				8.5	9.6
NNE	.2	.7	1.2	.4	.2	.0						2.7	8.9
NE	.1	.6	1.0	.3	.1	.0	.0					2.4	8.4
ENE	.1	.2	.2	.1	.0	.0		.0				.5	8.8
E	.1	.4	.4	.1	.1	.0	.0					1.2	8.6
ESE	.4	.6	.7	.3	.3	.1	.0	.0				2.3	10.1
SE	.3	1.1	2.9	2.3	1.4	.3	.1	.0				8.4	12.1
SSE	.5	1.1	2.4	1.3	1.0	.2	.1	.0	.0			6.8	11.9
S	.7	2.4	3.8	1.4	.9	.2	.1	.0	.0			9.6	10.0
SSW	.2	.6	.9	.3	.2	.0	.0	.0	.0			2.2	9.5
SW	.4	.5	1.5	.6	.4	.0	.0	.0	.0			3.4	10.5
WSW	.4	.7	2.0	1.1	.6	.1	.0			.0		4.8	11.0
W	.8	1.2	3.4	1.5	.8	.1	.0	.0	.0			7.9	10.3
WNW	.2	1.1	2.4	1.0	.3	.0	.0	.0				5.0	9.7
NW	.4	2.4	4.9	2.2	1.0	.1	.0					11.0	9.6
NNW	.2	1.1	1.9	1.0	.2	.1	.0					4.9	10.3
VARBL													
CALM												18.9	
	4.3	17.8	33.0	15.4	5.2	1.3	.5	.1	.0	.0		100.0	8.3

TOTAL NUMBER OF OBSERVATIONS 28745

SOURCE: National Climatic Center, *SSMO (PART C)*.

USAFETAC FORM 0-8-5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

PORT MOLLER: INFORMATIONAL RESOURCES

- Port Moller Salmonid Resources
- Fish and Shellfish Important at Port Moller
- Biological Resources of Port Moller
- Port Moller Vicinity Mammals and Birds
- Dates of Freezeup and Ice Breakup - Alaska
- Climatological Summary - Cold Bay
- Surface Winds - Bristol Bay
- Surface Winds - Port Moller
- Surface Winds - Cold Bay

PORT MOLLER SALMONID RESOURCES

Sockeye juveniles leaving Bristol Bay tend to congregate in the Port Moller area (from shore to about 40 km offshore) where they begin feeding after leaving their rivers of origin. They are in the area from mid-June until late August. From Port Moller their movement is offshore into the Bering Sea. Using the adult run sizes to Bristol Bay and a 90 percent marine mortality an estimated 500 million juveniles could be in the Port Moller area in a given year. However, the number at any given date would be less, but would often be in the millions. The early marine life of juvenile salmon is considered critical to survival and at this time they would probably be more sensitive to oil spills due to other physiological stress they are dealing with (i.e., osmoregulatory changes, starvation from not feeding in Bristol Bay, new diet). This would also make any effect on their food (plankton) potentially detrimental.

Adult sockeye migrating to Bristol Bay pass Port Moller from about June 15 to July 1 (this would be peak abundances; the entire run would be spread out from June 1 to September 1; but abundances outside the peak would seldom be important). The abundance of adults on any one day would not equal the entire Bristol Bay run, but during the peak it would be several million. The mean run to Bristol Bay from 1956 through 1972 was 16.6 million with a range of 53.1 - 2.4 million.

* Note: In some years the fishery at Port Moller can be large, e.g., in 1971 the catch at Bear River and Herendeen Bay totalled nearly 2.5 million sockeye.

The information on salmon species other than sockeye is scanty, but their behaviour is similar. King salmon adults pass Port Moller earlier than sockeye, 75 percent of the run between June 14 and 28 (65 to 90 km offshore). Coho adults would be in the Port Moller area from mid-July till late August. Both king and coho are mostly transitory in the area as the local spawning stocks account for only five percent of the Bristol Bay catch. The rest are bound for the Naknek and Nushagak systems. Local spawning is in the Izembek and Nelson lagoon areas.

Chum salmon adults pass Port Moller between June 20 and July 10 about 40 to 95 km offshore. There is also some local spawning, so these fish would be in the area longer and closer to shore. Pink salmon adults pass Port Moller about the same time as the Bristol Bay sockeye run. Although there are local spawning stocks of all species, the evaluation should be based on the Bristol Bay runs passing by the area simply because of the greater numbers. Of all salmon in the area at least 90 percent are bound for the upper bay. Total run statistics for the non-sockeye species is not available but catch data is. Assuming a rate of exploitation of 50 percent (conservative) the runs to Bristol Bay during 1951 to 1967 by species were:

PORT MOLLER SALMONID RESOURCES (CONT'D)

SPECIES	ESTIMATED MEAN RUN
King	165,400
Coho	74,300
Chum	928,800
Pink (even years)	1,650,200

There is little information on juveniles of these four species but their behaviour is probably similar to sockeye. The pink and chum salmon leave freshwater earlier and would be in the Port Moller area in early to mid-June. The king and coho juveniles probably move through the area within the time frame of sockeye but no information is available.

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. Straty, R. R., *ECOLOGY AND BEHAVIOR OF JUVENILE SOCKEYE SALMON (Onchorhynchus Nerka) IN BRISTOL BAY AND THE EASTERN BERING SEA.* International Symposium for Bering Sea Study, Vol. 1, 1972.

2. State of Alaska, Department of Fish and Game Division of Commercial Fisheries. Bristol Bay Area, Annual Management Report, 1967.

3. Rodgers, D. E., *FORECAST OF THE SALMON RUN TO BRISTOL BAY IN 1974.* University of Washington Fisheries Research Institute, Circular 74-1, 1974.

4. Arctic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, prepared for the Department of the Army, Alaska District Corps of Engineers, February, 1974.

FISH AND SHELLFISH IMPORTANT AT PORT MOLLER[1,2,3]

Salmon - (no kings) plus Dolly Varden
Smelt - Capelin, Rainbow Smelt
Surf Smelt and Eulachen
Cods - Pacific Cod, Pollock, and Saffron Cod
Threespine Stickleback
Hexagramnids (three species)
Cottids (10 species)
Agonids or Sea Poachers (three species)
Snailfish
Sandlance
Gunnels
Flounder - Halibut, Starry Flounder
Yellowfin Sole, Rock Sole,
and Longhead Dab
King and Tanner Crabs

KING CRAB

Offshore areas off Port Moller are very important to king crab fishery. First, second, and third stage zoea were collected in surface hauls off Port Moller from mid-May through June. More were taken during the night indicating a diurnal migration. As development proceeds, the animal apparently moves to deeper water.[4] King crab larvae are off Port Moller from May 16 - June 15 with highest abundances found near shore.[5]

King crab may be characterized as a benthic feeding predator. Mollusks in 71 percent of stomachs (gastropods and pedypods), crustaceans 56 percent, and amphipods 31 percent.[6]

In laboratory rearing experiments, king crab zoea were fed trochophore larvae of [illegible] sp. and several kinds of polychaete larvae.[7]

YELLOWFIN SOLE

Yellowfin sole spawn in the offshore area of central Bristol Bay in July. The eggs develop in the surface layers at temperatures of 6.4°C to 11.4°C.

Yellowfin sole usually stop feeding in Winter but were noted to continue during the Winter of 1963-1964.[8]

Yellowfin sole feeds mainly on mysids, euphausids, shrimp, *(Pandalus borealis)*, and several mollusks.[9]

ROCK SOLE

Second in importance for flounders, rock sole spawn from March to June in Bristol Bay.[10] Eggs are demersal and adhesive.[11] Rate of hatching was found to be 6.4, 8.3, 10.9, and 15.3 days at 11, 9, 7 and 5°C under laboratory conditions.[12]

Feeds mainly on polychaetes and some mollusks.[9]

SOURCES:

1. McRoy, C., and A. Peden, *FISHES COLLECTED IN IZEMBEK LAGOON*, U.S. Fish and Wildlife Service, Izembek National Wildlife Range, Alaska, Wildlife Report No. 2: 4 p., N.D.

2. Tack, S. L., *THE SUMMER DISTRIBUTION AND STANDING STOCK OF THE FISHES OF IZEMBEK LAGOON, ALASKA*, University of Alaska, Masters Thesis, 1970.

3. Best, E.A., International Pacific Halibut Commission, Personal Communication.

4. Takeuchi, I., *ON THE DISTRIBUTION OF ZOEL LARVAE OF KING CRAB, Paralithodes camtschatica, IN THE SOUTHEASTERN BERING SEA IN 1960*, Hakkaido Regional Fisheries Research Laboratory Bulletin, 24:163-170, 1962.

5. Haynes, E.B., *DISTRIBUTION AND RELATIVE ABUNDANCE OF LARVAE OF KING CRAB, Paralithodes camtschatica, IN THE SOUTHEASTERN BERING SEA*, Natural Marine Fish. Serv. Fish. Bull., 72(3):804-812, 1974.

6. Feniuk, V.F., *ANALYSIS OF STOMACH CONTENTS OF KING CRAB*, Investigation, Tikhooksansky Institut Rybnozo Khozyoystov, 19:17-18, 1945.

7. Sato, S., and S. Tankaka, *STUDY ON THE LARVAL STAGE OF Paralithodes camtschatica (TILESIUS) II ON THE REARING*, Hokkaida Fishery Scientific Institution, Scientific Pages No. 3:18-30, 1940.

8. Fadeev, N.S., "The Fishery and Biological Characteristics of Yellowfin Soles in the Eastern Part of the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEASTERN PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

9. Skalkin, V. A., "Diet of Flatfishes in the Southeastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART I*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1963.

10. Shubnikov, D. A., and L. A. Lisovenko, "Data on the Biology of Rock Sole in the Southeastern Bering Sea," *SOVIET FISHERIES INVESTIGATION IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

11. Forrester, C.R. "Demersal Quality of Fertilized Eggs of Rock Sole (*Lepidopsetta bilineata*, Ayres)," *J. FISH. RES. BD., CANADA*, 21(6):1531-1532, 1964.

12. Forrester, C.R., "Rate of Development of Eggs of Rock Sole (*Lepidopsetta bilineata*, Ayres)," *J. FISH. RES. BD., CANADA*, 21(6):1533-1534, 1964.

BIOLOGICAL RESOURCES OF PORT MOLLER

AREA	Port Moller - Izembeck
SUB-AREA	
SEASON	Summer
HABITAT	Lagoon and Coastal Basins

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Plankton[1] *Chaetoceros* *Rhizosolenia* *Thalassiothrix*	2.2 - 16.2 mg C/cu m /Hr.					High						Peaks To 26.8 - 194.0 mg in July.
Pacific Herring[2,3] *Clupea harengus pallasi*	In Excess of 90 kg/Hr.	High	Med. - High	Low	-	High		April - June	Shallow Pelagic	Adult	Zooplankton Euphausids	Spawn abundantly near Port Moller and Hagemeister Island
Pacific Herring[2,3] *Clupea harengus pallasi*		High	-	-	-	High		April - Aug.	(Winter out on Pribilofs)	Larvae		Juvenile herring school in kelp beds in Summer Juveniles move offshore in early Autumn Adults remain in inshore waters and bays in Summer, leave in September-October.
Starry Flounder *Platichthys stellatus*	High?	-	-	-	-	Med.		May - June	Winters on Slope Summers Shallows	Adults	Polychaetes Shrimps Mollusks	Two forms (Coastal and Marine).

BIOLOGICAL RESOURCES OF PORT MOLLER (CONT'D.)

AREA Port Moller - Izembek
SUB-AREA
SEASON
HABITAT Sand Beaches of Lagoons

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Razor Clam[4] *Siliqua patula*	High	High	Med.	Low	Med.	High		June-August		Adult		
Razor Clam[4] *Siliqua patula*								Eight-week Period		Larvae		
Butter Clams[5] Great Cockle Littleneck	Med?											

BIOLOGICAL RESOURCES OF PORT MOLLER (CONT'D.)

AREA Port Moller
SUB-AREA Deepwater (Shelf) Area North
SEASON
HABITAT Sandy Mud to Muddy Sand Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Rock Sole[6-8] *Lepidopsetta bilineata*	High 90-270 kg/Hr.	Low	High (Poten.)	-	-	High	-	February-May	Summer 0-120m Winter 0-180m	Adults	Polychaetes Mollusks Shrimps	Estimated Potential Annual Yield 90. F - 136,000 Metric Tons Associated with Yellowfin Sole migrates into shallows in Summer; Disbursed.
Yellowfin Sole[7] *Limanda aspera*	Med.	Low	High	-	-	High		June-August	Summer 0-120m Winter 0-180m	Adults	Shrimp Bivalve Mollusks	Migration into shallows in Summer from Unimak Bank.
Flathead Sole[7] *Hippoglossoides elassodon*	High > 270 kg/Hr.	Low	Med.	-	-	High		February-May	Summer 0-160m Winter 0-400m	Adults	Ophiuroids Shrimps Amphipods Mollusks	Winter: Separate, large concentration over all of slope and lower part of shelf. Summer: small, sparse concentration in shoal waters. Estimated 27,000 to 36,000 metric ton yield.
Starry Flounder[7] *Platichthys stellatus*	Low	Low	0 to Low	-	-	Low		May-June	Winters in River mouths or on Bay Slope	Adult	Polychaetes Shrimps Mollusks	Two forms (Coastal and Marine) ?
Arrowtooth Flounder[7] *Atheresthes stomias*	Low - Med.	Low	Low	-	-	Low		April-May	?	Adults	Shrimps Fish Herring Sandlance	Estimated 18,000 to 36,000 metric ton yield.

BIOLOGICAL RESOURCES OF PORT MOLLER (CONT'D.)

AREA: Port Moller
SUB-AREA: Deepwater (Shelf) Area North
SEASON:
HABITAT: Sandy Mud to Muddy Sand Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	LIFE HISTORY: SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Pacific Halibut[9,10] *Hippoglossus stenolepis*	90-270 kg/Hr.	Low	High	Low	Low	High?		November - February	>80 m	Adults	Fish: Yellowfin Sole, Pollock, Sandlance	Generally in Bay are younger and smaller fish. In area primarily January to May
Pacific Halibut *Hippoglossus stenolepis*	-	High if exposed)	-	-	-	High		6 to 7 month period	Pelagic Midwater to surface	Eggs/ Larvae		Larvae often carried into shallow waters.
Longhead Dab *Limanda proboscidea*	Low	Low	-	-	-	Low		July to August	Winter in 100 m Summer 30-90 m	Adults		
Alaska Plaice *Pleuronectes quadrituberculatus*	Low	Low	-	-	-	Low		May to June	Winter 100-200 m Summer 30-100 m	Adults		Rare on slope in Winter. Moves into shallows in Summer but does not form concentrations.

BIOLOGICAL RESOURCES OF PORT MOLLER (CONT'D.)

AREA: Port Moller
SUB-AREA: Deepwater Area North
SEASON:
HABITAT: Soft Sediments-Sandy Mud to Muddy Sand 72-105 M

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Echinoderm Fauna[11] *Echinarchinus parma* *Asterias rathbuni* *Leptasterias polaris* *Ophiura sarsi*	>25g/m^2					Medium (Flatfish Food Organisms) Esp. Flathead Sole						Especially abundant
King Crab *Paralithodes camtschatica*	High 50-100									Larvae	Diatoms	
Walleye Pollock[12,13] *Theragra chalcogramma*	In excess of 1,800 kg/Hr.	Low	High	-	-	High		February-May		Adults	Zooplankton and small Fish	Annual worth of $500 million to U. S. Early Summer (45-80 m) catches > 90 kg/Hr. Annual Harvest 86,000 to 110,000 metric tons
Pacific Cod[14] *Gadus macrocephalus*	1,300 kg/Hr. Max. Catches	Low	High	Low		High		January-April	65-80m	Adults	Bottom and Crustaceans	Potential yield of 17 to 23 metric tons. Spawn in waters 100 to 250 m.
Sablefish *Anoplopoma fimbria*	Low		Med.						365 to 730 m		Small Fish, Worms and Crustaceans	Potential yield 13.6 to 22.7 thousand metric tons.
Pacific Ocean Perch[15] *Sebastes alutus*	Low-Med.	Low	High	-	-	Med.		September-October Spawning (Cop.) March-April Larvae expelled 360 to 420 m				20 to 60 m above rocky bottoms. Potential yield 22.7 to 45.4 thousand metric tons for all Bering. Juveniles found in colder, shallower waters. Larvae rec. southeast of Pribilofs.

BIOLOGICAL RESOURCES OF PORT MOLLER (CONT'D.)

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. Arctic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, prepared for the Department of the Army, Alaska District, Corps of Engineers, February 1974.

2. Shaboneev, I. E., "Biology and Fishing of Herring in the Eastern Part of the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART IV*, P. A. Moisseev, ed., Israel Program for Scientific Translations, 1965.

3. Musienko, L. N., "Reproduction and Development of Bering Sea Fishes," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

4. U. S. Department of the Interior, *UNIMAK ISLAND WILDERNESS STUDY, ALEUTIAN ISLANDS NATIONAL WILDLIFE REFUGE, THIRD JUDICIAL DISTRICT, ALASKA*, Wilderness Study Report, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife.

5. Arctic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, prepared for the Department of the Army, Alaska District, Corps of Engineers, February 1974.

6. Arctic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, prepared for the Department of the Army, Alaska District, Corps of Engineers, February 1974.

7. Fadeev, N. S., "Comparative Outline of the Biology of Flatfishes in the Southeastern Part of the Bering Sea and Conditions of Their Resources," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART IV*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

8. Shubnikov, D. A., and L. A. Lisovenko, "Data on the Biology of Rock Sole of the Southeastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

9. Novikov, N. P., "Basic Elements of the Biology of the Pacific Halibut, *Hippoglossus hippoglossus stenolepis* Schmidt, in the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

10. Shuntov, V. P., "Distribution of Greenland Halibut and Arrow-toothed Halibuts in the North Pacific," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART IV*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1965.

11. Ivanov, B. G., "Quantitative Distribution of Echinodermata on the Shelf of the Eastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

12. Faculty of Fisheries - several reports, 1964-1967, the OSHARU MARU cruises 4, 9, 14, 19, *DATA RECORD OF OCEANOGRAPHIC OBSERVATIONS AND EXPLORATORY FISHING*, No's. 8, 9, 10, and 11, Hokkaido University (from Source No. 1).

13. Serobaba, I. I., "Distribution of Walleye Pollock *Theragra chalcogramma* (Pallas), in the Eastern Bering Sea and Prospects of Its Fishery," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

14. Faculty of Fisheries - several reports, 1964-1967, the OSHARU MARU cruises 4, 9, 14, 19, *DATA RECORD OF OCEANOGRAPHIC OBSERVATIONS AND EXPLORATORY FISHING*, No's. 8, 9, 10, and 11, Hokkaido University (from Source No. 1).

15. Paraketsov, I. A., "On the Biology of *Sebastodes alutus* of the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART I*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1963.

PORT MOLLER VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1, 2]	Beaches Grass Flats	Important area with dense populations. Heavy beach use and stream feeding on salmon.
Wolves and Wolverines[1, 2]	Beaches Grass Flats	Possible impact on food resources.
Moose[1]	Willow Flats	Expanding population. Year-long concentration area just east of Port Moller. Calving on coastal plain would be vulnerable to pollution and cleanup.
Caribou[1]	Tundra Lowlands Willow Flats	There are 15,000 estimated for the Peninsula. Port Moller is dividing area for two distinct herd groups. Important wintering area westside of Port Moller.
Aquatic Furbearers[2]	Flats Estuaries	Light population presumed but these highly vulnerable to oil spills.
Harbor Seal[1]	Beaches Estuaries	An estimated 1,500 were harvested annually in Port Moller until protected recently under Marine Mammal Protection Act.
Northern Fur Seal[1]	Pelagic	Minor Spring and Fall migration stocks.
Sea Lions[2]	Rocky Coves Beaches	Estimated 50,000 sea lions on Alaska Peninsula. Local population concentrations as follows: Wosnesenkki Island 300, Jude Island 3,000 including pups, Shumagin Island 400, Unga Island 30, The Whaleback 600, Haystack 3,100.
Walrus[1]	Pelagic	Minor occurences in Winter and Summer.
Whales and Porpoises[1]	Pelagic	Several species during Summer, principally beluga whales.
Sea Otter[1]	Nearshore Seas Bays	Population expanding. Major Winter ice off in 1971 and 1972. Few survivors in Port Moller but population recovery expected.
Ducks[1]	Nearshore Seas Marsh Flats Estuaries	Major wintering in main bays. High productivity estimated at 32 breeding pairs per square mile west of Port Moller.
Geese[1]	Nearshore Seas	Migration area. Brooding ground. Major production area but population estimate not available.
Swans[1]	Nearshore Seas Beaches Estuaries	Major swan production area. Two whistling swans per square mile. Major migration area.

PORT MOLLER VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Seabirds[2]	Beaches	No major colonies, some beach colonies.
Shorebirds[2]	Beaches Mud Flats	Possible impact on food items.
Upland Game Birds[2]		
Raptors[2]		

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

DATES OF ICE BREAKUP AND FREEZEUP

Place	Waters	Ice breakup			Ice freezeup			Ave years record	Period
		Average	Earliest	Latest	Average	Earliest	Latest		
Gulf of Alaska									
Susitna	Susitna River	May 1	4/12/41	5/10/46	Nov 1	10/18/33	11/14/36	12	1933 - 1946
Talkeetna	...do	May 8	4/12/41	5/25/52	Dec 2	11/12/30	12/23/47	12	1918 - 1952
Kasilof	Kasilof River	Apr. 13	3/27/41	4/29/46	Dec 3	11/13/45	12/24/48	10	1937 - 1947
Kenai	Kenai River	Apr. 2	3/18/52	4/14/51	Dec. 10	11/23/51	12/26/37	8	1931 - 1952
Anchorage	Ship Creek	Mar. 20	2/16/44	4/17/42	Nov 24	11/10/36	12/10/36	21	1915 - 1953
Bering Sea									
Egegik	Egegik River	Apr 14	3/16/41	5/ 1/39	Dec 12	11/12/42	1/11/39	10	1937 - 1952
Naknek	Naknek River	Apr. 9	3/19/41	4/25/40	Nov. 17	10/17/30	12/15/17	7	1916 - 1951
Koggiung	Kvichak River	May 4	4/26/38	5/13/40	Dec 22	11/23/30	1/30/41	3	1937 - 1940
Dillingham	Nushagak Bay	May 9	4/25/26	5/27/52	Nov. 7	10/16/32	12/22/40	10	1919 - 1952
Kanakanak	...do	May 2	4/17/40	5/22/39	Nov 20	10/14/42	12/21/38	4	1937 - 1943
Platinum	Goodnews Bay	May 1	4/ 8/42	5/25/52	Nov 10	10/23/30	12/12/47	12	1928 - 1952
Kwinhagak	Kuskokwim Bay	May 1	4/10/45	5/17/44	Nov 15	10/20/29	12/20/38	10	1929 - 1952
Bethel	Kuskokwim River	May 15	4/24/40	5/28/52	Oct. 20	10/ 8/28	11/24/51	27	1923 - 1952
Crooked Creek	...do	May 7	4/22/40	5/23/52	Nov. 18	11/ 3/39	12/ 2/52	12	1937 - 1952
McGrath	...do	May 10	4/24/40	5/24/52	Nov 5	10/23/41	11/15/52	12	1939 - 1952
Mekoryuk Nunivak Island	Mekoryuk River	May 12	4/18/50	5/30/46	Nov 27	11/20/52	12/13/47	5	1943 - 1951
Gambell, St Lawrence Island		May 26	5/ 1/43	7/ 1/50	Nov 21	10/15/40	12/16/40	10	1940 - 1952
Savoonga, St Lawrence Island		May 26	4/25/48	6/17/45	Nov 19	9/20/30	12/13/40	10	1929 - 1949
Hooper Bay	Hooper Bay	May 26	5/15/42	6/ 4/45	Nov. 12	10/19/26	11/20/41	4	1926 - 1945
St Michael	Norton Sound	June 8	5/19/12	7/ 3/01	Nov 10	10/10/84	12/ 7/81	53	1876 - 1952
Unalakleet	Unalakleet River	May 17	4/28/40	5/30/52	Oct 25	10/ 8/30	11/19/37	14	1937 - 1952
Moses Point	Kwiniuk River	May 24	5/ 2/51	6/11/48	Oct 30	10/ 1/51	11/ 2/52	6	1943 - 1952
Golovin	Golovnin Bay	May 23	5/13/40	6/14/39	Nov 2	10/ 8/42	11/19/37	6	1937 - 1943
White Mountain	Fish River	May 21	5/ 5/40	6/ 2/37	Oct. 14	9/27/31	11/ 9/28	24	1923 - 1951
Solomon	Solomon River	May 20	5/ 1/42	5/30/45	Oct. 29	10/10/40	11/29/48	10	1940 - 1952
Council	Niukluk River	May 17	4/27/40	5/31/52	Oct. 30	10/13/20	11/ 9/40	12	1920 - 1952
Nome	Norton Sound	May 20	4/20/42	6/28/48	Nov 12	10/13/18	12/13/47	50	1900 - 1952
Teller	Grantley Harbor	June 7	5/12/36	6/18/39	Nov 10	10/13/42	12/26/50	16	1936 - 1952
Yukon River									
Akulurak	Kwikluak Pass	May 27	5/20/42	6/ 4/20	Oct 24	10/11/30	11/ 7/23	14	1917 - 1948
Hamilton	22 Nautical miles above Apoon Pass	May 22	5/ 6/40	6/ 5/52	Oct 25	10/15/30	11/ 2/38	14	1938 - 1952
Anacharak	85	May 20	5/ 3/38	6/ 6/52	Nov 13	11/ 1/30	12/22/40	12	1937 - 1952
Pilot Station	115	May 17	5/ 1/26	5/24/24	Nov 8	10/27/24	11/13/25	5	1924 - 1943
Russian Mission	185	May 12	4/25/40	5/25/38	Nov 4	10/21/28	11/15/37	8	1928 - 1944
Holy Cross	257	May 17	4/25/40	5/28/52	Oct 31	10/12/31	11/30/34	32	1917 - 1952
Galena	461	May 17	5/ 8/51	5/26/52	Nov 6	10/11/47	12/ 8/50	10	1943 - 1952
Ruby	526	May 15	4/30/40	5/22/20	Nov 7	10/26/17	11/18/37	11	1917 - 1946
Tanana	628	May 14	4/29/40	5/25/35	Nov. 4	10/13/30	11/22/37	33	1917 - 1952
Rampart	688	May 16	5/ 1/30	5/25/52	Nov 8	10/13/20	11/23/45	21	1917 - 1952
Fort Yukon	896	May 14	5/ 7/40	5/22/27	Oct 28	10/14/41	11/15/52	30	1918 - 1952
Coal Creek	1,002	May 12	5/ 7/43	5/18/45	Nov 9	11/ 1/38	11/30/40	8	1938 - 1950
Eagle	1,088	May 8	4/25/40	5/18/52	Nov 18	10/18/30	12/11/40	29	1917 - 1952
Dawson, Canada	1,197	May 8	4/28/40	5/16/45	Nov 17	11/ 3/41	12/18/42	12	1917 - 1947
Arctic Ocean									
Wales	Bering Strait	June 8	5/15/47	6/30/40	Dec 3	10/ 8/48	1/ 8/51	16	1927 - 1952
Shishmaref	Arctic Ocean	June 22	5/30/36	7/ 8/33	Nov 10	10/ 6/30	12/18/34	18	1931 - 1952
Candle	Kiwalik River	May 18	5/ 5/43	5/27/27	Oct 17	10/10/42	10/23/43	8	1922 - 1950
Deering	Inmachuk River	June 4	5/11/43	6/30/41	Oct 23	10/ 3/46	11/ 4/41	4	1937 - 1948
Kotzebue	Kotzebue Sound	May 31	5/17/40	6/ 8/45	Oct 23	10/ 2/30	11/ 5/38	14	1929 - 1952
Selawik	Selawik River	May 28	5/13/40	6/ 7/45	Oct 17	10/ 3/46	10/30/38	12	1927 - 1952
Noorvik	Kobuk River	May 29	5/18/25	6/11/22	Oct 11	9/26/40	10/25/22	17	1918 - 1952
Kiana	-- do	May 18	5/ 7/40	5/29/39	Oct 18	10/10/39	11/ 4/38	6	1938 - 1944
Kobuk	-- do	May 19	5/11/43	5/29/45	Oct 21	10/ 8/39	11/ 2/38	12	1937 - 1952
Shungnak	-- do	May 21	5/12/41	5/29/45	Oct 16	10/ 7/19	10/25/40	8	1919 - 1950
Kivalina	Kivalina River	May 22	5/15/43	5/27/48	Oct 25	10/15/48	11/ 1/46	6	1943 - 1952
Point Hope	Arctic Ocean	June 20	5/30/27	7/ 8/46	Nov 11	10/ 6/42	12/19/47	8	1927 - 1951
Point Lay	-- do	June 24	6/ 1/43	7/10/53	Nov 4	10/12/43	11/27/48	4	1943 - 1953
Wainwright	-- do	June 20	6/ 7/44	7/26/48	Oct 2	9/26/48	10/ [illegible]/45	7	1939 - 1953
Point Barrow	-- do	July 22	6/15/44	8/22/31	Oct 3	8/31/27	12/19/47	31	1920 - 1953

SOURCE: U. S. Department of Commerce and Coastal and Geodetic survey, *PACIFIC AND ARCTIC COASTS - ALASKA, CAPE SPENCER TO BEAUFORT SEA* Seventh Edition (October 3, 1974, U. S. Coast Pilot Volume 9.

CLIMATOLOGICAL SUMMARY

COLD BAY, ALASKA (Cold Bay Airport). 55°12'N, 162°43'W. Elevation (ground) 94 feet WB-1961

Month	Air temperature (°F.) Normal: Daily maximum	Daily minimum	Monthly	Extreme: Record highest	Record lowest	Precipitation (inches): Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	Humidity (percent): 7 00 a.m. Local time	1 00 p.m. Local time	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				17	18		16	11	6	6	6	6			6	6	6	6	16	11	6	6
Jan.	33.4	24.7	29.1	46	5	2.52	2.48	7.8	86	84	15.8	SSE			8.4	1	6	24	17	3	0	4
Feb	32.7	24.[illegible]	29.4	50	-9	2.26	2.49	8.0	85	81	15.6	SSE			8.4	2	4	22	16	2	0	2
Mar	34.4	24.2	29.7	54	-7	1.89	1.39	8.5	84	76	15.6	NNW			7.8	3	7	21	17	3	0	2
Apr	38.[illegible]	[illegible]	34.2	60	4	1.34	1.76	5.7	85	70	15.6	SSE			8.7	1	6	23	12	2	0	1
May	44.1	36.9	39.5	62	21	1.62	2.24	1.2	86	78	14.[illegible]	SSE			9.1	*	3	28	16	*	0	2
June	50.4	40.9	45.7	69	29	2.64	2.02	T	87	77	13.5	SSE			9.2	1	2	27	14	0	0	2
July	54.4	45.5	50.0	77	36	2.14	1.20	0.0	91	82	13.0	SSE			9.5	*	2	28	16	0	0	6
Aug.	55.3	47.9	52.1	78	33	3.57	2.17	0.0	92	84	14.6	SSE			9.5	0	2	29	19	0	0	3
Sep.	51.5	43.4	47.5	70	33	3.57	1.88	T	88	79	14.6	SSE			9.2	0	3	27	18	0	0	1
Oct	44.[illegible]	[illegible].5	42.5	69	20	4.39	2.52	1.0	85	77	15.5	WSW			8.3	2	4	25	21	*	0	1
Nov	38.7	[illegible]	34.7	24	8	3.82	2.75	5.6	84	[illegible]	15.4	SSE			8.6	1	6	23	20	2	0	*
Dec	34.[illegible]	25.4	29.8	47	-9	2.[illegible]	1.70	7.8	83	82	15.6	NNW			8.6	1	5	25	18	2	0	3
Year	42.8	34.0	38.4	78	-9	33.20	2.75	47.2	86	80	1[illegible].1	SSE			8.8	12	50	303	206	15	0	27

SOURCE: U. S. Department of Commerce and Coastal and Geodetic survey, *PACIFIC AND ARCTIC COASTS - ALASKA, CAPE SPENCER TO BEAUFORT SEA*, Seventh Edition (October 3, 1974), U. S. Coast Pilot Volume 9.

BRISTOL BAY - SURFACE WINDS

Station	Winter		Summer		Fastest Mile		2nd Fastest Mile	
	Prevailing Direction	Mean Speed (mph)	Prevailing Direction	Mean Speed (mph)	Direction	Speed (mph)	Direction	Speed (mph)
Platinum	NW; N; NE	13	S; SW	13	Several	>47		
Cape Newenham	N	11	S	9		79		76
Dillingham	N; NE		SW					
King Salmon	N		S; SW	11	N	71	N	69
Port Heiden								
Port Moller	N; NW	10	S	13	SE	63	S	54
Cold Bay	NW; SW; SE	18	SE; NW	16	SE	73	SE; NW	67
Cape Sarichef	NW; W; SE		W; SE					
Dutch Harbor	NW; SE		SE					
St. Paul Island	E; N; S; NW	21	S; SE; SW; NW	14	NW	82	NE	72

SOURCE: Swift, W. H., R. E. Brown, L. V. Kinnel, M. M. Orgel, P. L. Petersen, W. W. Waddell, *GEOGRAPHICAL ANALYSIS OF OIL SPILL POTENTIAL ASSOCIATED WITH ALASKAN OIL PRODUCTION AND TRANSPORTATION SYSTEMS*, Pacific Northwest Laboratory, Division of Memorial Institute to the United States Coast Guard, February 1974, Final Report No. CG-D-79-74.

DATA PROCESSING DIVISION
ETAC/USAF
AIR WEATHER SERVICE/MAC

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND
DIRECTION AND SPEED
(FROM HOURLY OBSERVATIONS)

25625 — PORT MOLLER ALASKA AFS (STATION NAME) — 59-69 (YEARS) — ALL (MONTH)

ALL WEATHER (CLASS) — ALL (HOURS (L.S.T.))

CONDITION

SPEED (KNTS) DIR	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥56	%	MEAN WIND SPEED
N	[illegible]	2.4	2.5	1.4	.9	.1	.0					7.5	9.3
NNE	.4	1.7	1.5	.7	.1	.0						5.0	7.9
NE	[illegible]	2.4	1.8	.7	.1	.0	.0					5.6	7.4
ENE	.3	.8	.5	.1	[illegible]	.0						1.9	6.7
E	.3	.7	.4	.1	[illegible]	.0	.0					1.7	6.6
ESE	.2	.2	[illegible]	.3	.2	.0	.0	.0				1.9	9.9
SE	.2	.3	.7	.6	.6	.2	.1	.0		.0		3.0	13.1
SSE	.1	.9	2.3	3.0	2.2	.6	.3	.1	.0			9.6	14.4
S	.5	[illegible]	4.1	3.5	2.1	.6	.2	.0	.0			13.6	11.8
SSW	.2	.9	1.0	.3	.2	.0	.0					2.8	8.8
SW	.3	1.1	1.6	.8	.3	.0	.0					4.0	9.4
WSW	.2	.7	1.3	.4	.2	.1	.0					3.3	10.1
W	[illegible]	[illegible]	2.4	1.4	.5	.1	.0					6.6	9.6
WNW	.2	1.1	1.4	1.1	.6	.1	.0					4.5	10.8
NW	[illegible]	[illegible]	2.2	1.6	1.0	.3	.1	.0				7.4	11.2
NNW	.3	1.4	1.7	1.6	1.0	.3	.1	.0				6.3	11.6
VARBL													
CALM												15.3	
	4.7	21.3	26.4	10.5	9.9	2.8	.8	.2	.0	.0		100.0	8.9

TOTAL NUMBER OF OBSERVATIONS 28991

SOURCE: National Climatic Center, *SSWO (PART C)*.

USAFETAC FORM JUL 64 0-8-5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

DATA PROCESSING DIVISION
ETAC, USAF
ASHEVILLE, N. C. 28801

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND
DIRECTION AND SPEED
(FROM HOURLY OBSERVATIONS)

25624 COLD BAY ALASKA UDAS (STATION / STATION NAME) 42-68 (YEARS) ALL (MONTH)

ALL WEATHER (CLASS) ALL (HOURS (L.S.T.))

CONDITION

SPEED (KNTS) DIR	1-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	≥ 56	%	MEAN WIND SPEED
N	.2	.7	1.3	1.7	1.2	.6	.1	.0	.0	.0		6.3	13.6
NNE	.2	.3	.9	.4	.7	.6	.2	.1	.0	.0		3.9	16.7
NE	.2	.4	.4	.2	.1	.1	.0	.0	.0	.0		1.3	10.3
ENE	.1	.3	.3	.1	.1	.1	.0	.0	.0	.0	.0	1.1	12.4
E	.1	.3	.3	.2	.2	.3	.1	.0	.0	.0		1.6	14.1
ESE	.2	.3	.7	.8	.8	.8	.3	.2	.0	.0	.0	4.3	18.3
SE	.3	.7	1.8	2.8	2.3	2.2	1.2	.3	.1	.0	.0	12.0	18.3
SSE	.2	.7	1.8	3.4	3.2	2.9	1.4	.6	.1	.0	.0	14.3	18.7
S	.3	.6	.7	.8	.6	.5	.2	.1	.0	.0	.0	3.8	14.4
SSW	.2	.3	.3	.2	.1	.1	.0	.0	.0	.0	.0	1.2	11.3
SW	.4	.5	.6	.3	.3	.1	.1	.0	.0	.0		2.2	12.3
WSW	.2	.5	1.2	2.0	1.4	.9	.4	.1	.0	.0	.0	6.8	15.7
W	.3	.8	1.2	2.5	1.4	.8	.2	.1	.0	.0		8.0	13.6
WNW	.4	1.2	2.8	3.1	1.5	.7	.2	.0	.0			9.9	12.6
NW	.3	1.0	2.4	2.6	1.5	.9	.3	.1	.0	.0		9.1	13.6
NNW	.2	.8	2.0	2.9	1.9	1.2	.4	.1	.0	.0	.0	9.6	13.0
VARBL													
CALM												4.4	
	3.2	9.3	19.8	24.5	17.7	12.9	3.4	2.0	.5	.1	.0	100.0	14.6

TOTAL NUMBER OF OBSERVATIONS 193525

SOURCE: National Climatic Center, *SSMO (PART C)*.

USAF ETAC FORM 0-8-5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

KVICHAK BAY: INFORMATIONAL RESOURCES

- Kvichak Bay Salmonid Resources
- Fish Important at Kvichak Bay
- Biological Resources of Kvichak Bay
- Kvichak Bay Vicinity Mammals and Birds
- Climatological Summary - King Salmon
- Surface Winds - King Salmon

KVICHAK BAY SALMONID RESOURCES

The Kvichak river is the largest single producer of sockeye salmon in the world. The runs to the Naknek-Kvichak District have varied from one to nearly fifty million sockeye in recent years. The variation of runs in this district determines the magnitude of the entire Bristol Bay run since it constitutes up to 90 percent of the total.

Juvenile sockeye move through the spill site on their seaward migration from May 15 to July 15. The peak abundance would be about mid-June. They migrate along the Alaska Peninsula coastline rather hurriedly until they reach the area around Port Moller where they slow down and start feeding. Therefore, the concentration of juveniles at the spill site would probably never be great but would always be transitory. Nevertheless, at the peak of migration the abundance could be several million on any one day. Adult sockeye on their spawning migration would start appearing in the area in early June and peak about July 1 to 5. The fishery usually occurs from June 20 through July with 90 percent of the catch taken in the mid 15 to 20 days. The fish often congregate at the river mouths and inner bay before moving into freshwater, so the abundance at the spill site could be large, potentially 20 to 40 million.

The total economic value of the fishery is difficult to determine and the data for just the Naknek-Kvichak District is not available. However, the Bristol Bay sockeye fishery is the economic base of the entire area and the Naknek-Kvichak is the largest contributor.

Information is available for the entire Western Alaska and a proportion of 60 to 70 percent is a good estimate of the Naknek-Kvichak portion of this total. For the years 1967 to 1971 the mean annual value of sockeye catches to the fishermen was approximately $8,600,000.00 (2.9 - 18.3) and the wholesale value of the products was $16,400,000.00 (8.2 - 31.1).

No known spawning in the Bay itself. In marine environment, adults live in 1 to 10 m depth from surface and juveniles live in 1 to 2 m from surface. Adults and juveniles apparently do not feed in the Bay. Compared to the sockeye salmon runs the other salmon species are of little importance except as an "economic buffer" in years of low sockeye abundance. The addition of these species do little to change the "critical time frame". The king salmon (adults) enter the bay ahead of the sockeye June for the most part. Chums and pink salmon enter about the same time as the sockeye, usually with the late part of the run. The coho enter late, usually late July - early August. The juvenile outmigrants leave within the time frame of the sockeye smolts, although pink and chum fry leave during the early Summer, late May - early June.

The following values are to the fishermen based on mean catches (1951 - 1967) and 1967 prices to independent fishermen:

KVICHAK BAY SALMONID RESOURCES (CONT'D.)

SPECIES	VALUE
King	$17,962 (based on medium sized king)
Coho	2,072
Pink	
total	5,113
odd	25
even	10,838
Chum	72,396

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. Straty, Richard R., *ECOLOGY AND BEHAVIOR OF JUVENILE SOCKEYE SALMON (Oncorhynchus nerka) IN BRISTOL BAY AND THE EASTERN BERING SEA*, International Symposium for Bering Sea Study, Vol. 1, 1972.

2. Fredin, R. A., S. Pennoyer, K. R. Middleton, R. S. Roys, S. C. Smedley and A. S. Davis, *INFORMATION ON RECENT CHANGES IN SALMON FISHERIES OF ALASKA AND THE CONDITION OF THE STOCKS*, I.N.P.F.C. Doc. No. 1134, 1968.

3. Mathews, Stephen B., *THE ECONOMIC CONSEQUENCES OF FORECASTING SOCKEYE SALMON (Oncorhynchus nerka, WALBAUM) RUNS TO BRISTOL BAY, ALASKA*, Ph.D Thesis, University of Washington, 1967.

4. Hartman, W. L., W. R. Heard and B. Drucker, "Migratory Behavior of Sockeye Salmon Fry and Smelts," *J. FISH. RES. BD. CANADA*, 24(10):2069-2099, 1967.

5. State of Alaska Department of Fish and Game. Statistical Leaflet. Published Annually.

6. State of Alaska Department of Fish and Game. Division of Commercial Fish., Bristol Bay Area, Annual Management Report, 1967.

FISH IMPORTANT AT KVICHAK BAY

Yellowfin Sole
Starry Flounder
Longhead Dab
Cottids
Herring
Tom Cod
Greenling
Smelt
Sandlance
Sea Poachers
King Salmon (one only)

LONGHEAD DAB

The longhead dab spawns in June and may continue until early August. It spawns in the littoral areas shallower than other flatfish species. Spawning observed at 26 to 30 m at 2.2^{o} to $2.4^{o}C$.[2]

SOURCES:

1. Best, E. A., International Pacific Halibut Commission, Personal Communication.

2. Musienko, L. N., "Reproduction and Development of Bering Sea Fishes," *SOVIET FISHING INVESTIGATION IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

BIOLOGICAL RESOURCES OF KVICHAK BAY

AREA: Inner Bristol Bay
SUB-AREA: Naknek/Kvichak
SEASON:
HABITAT: Intertidal - Shallows Soft/Sand

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Razor Clam [1, 2] *Siliqua patula*		High	Low	Med.	Med.			July	Inter-tidal	Larvae July to Nov. Setting August to November		
Soft Shell Clam [3] *Macoma ?*	Med.	High		Med.	Low							
Tanner Crab [4] *Chionoecetes opilio*	High	High When Exposed	High						55 to 90 m	Adults		Center of Bay to Western Edge
General Zooplankton: [5] Mysidae *Acartia tonsa* *Eurytemora sp.* *Centropages*	Low	High	-	-	-	High		-	Intertidal Shallow Subtidal		Phytoplanters	Naknek River Estuary
Amphipod *Pontoporeia sp.*	High (to 6.25/ft.2) in Places	High	-	-	-	High			Intertidal Shallow Subtidal		-	Naknek River Estuary

BIOLOGICAL RESOURCES OF KVICHAK BAY (CONT'D.)

AREA: Inner Bristol Bay
SUB-AREA: Naknek/Kvichak
SEASON:
HABITAT: Intertidal Shallows - Soft Sand

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Polychaete Worm	High (to $30/ft^2$) in Places	High	-	-	-	High		Summer	Intertidal Shallow Subtidal		Detritus	Naknek River Estuary
Softshell Clam Macoma sp.	High (to $30/ft^2$) in Places	High	-	Low	Low	High		Spring to Summer				

BIOLOGICAL RESOURCES OF KVICHAK BAY (CONT'D.)

AREA Inner Bristol Bay
SUB-AREA
SEASON Summer
HABITAT Pelagic

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Zooplankton [6]						High						Volume decreases in June and July when seaward migrating smolts enter waters.
Pacific Herring [7,8,9] *Clupea harengus pallasi*	Low	High	Low	-	-	High		April to June	Shallow Pelagic to 70 m	Adults and Dev. Eggs	Zooplankton Euphausiids	Spawn abundantly near Pt. Moller and Hagemeister Island
Pacific Herring *Clupea harengus pallasi*				-	-			April to August		Larvae		Juvenile Herring school in kelp beds in Summer. In Bay late Spring to early August. Juveniles move offshore in early Autumn. Adults remain in inshore waters and bays in Summer, leave in September to October.

BIOLOGICAL RESOURCES OF KVICHAK BAY (CONT'D.)

AREA: Inner Bristol Bay
SUB-AREA: Naknek/Kvichak
SEASON:
HABITAT: Shallows and Intertidal, Sand and Gravel with Mud

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Pacific Herring[10] *Clupea harengus pallasi*	High (Periodically)	High (Periodically)	Med.	-	-	High			Shallow Subtidal			Naknek River Estuary
Arctic Smelt *Osmerus mordax dentex*	High (Periodically)	High (Periodically)	-	-	-	High			Shallow Subtidal			Naknek River Estuary
Starry Flounder *Platichthys stellatus*	Medium to Low	Low	-	-	-	Med.			Shallow Subtidal			Naknek River Estuary
Threespine Sticklebacks *Gasterosteus aculeatus*	Med.	Med.	-	-	-	Low			Shallow Subtidal			Naknek River Estuary
Ninespine Sticklebacks *Pungitius pungitius*	Low	Med.	-	-	-	Low			Shallow Subtidal			Naknek River Estuary
(Hybrid) Sole *Inopsetta ischyra*	High	Low	-	-	-	Med.			Shallow Subtidal			Naknek River Estuary

BIOLOGICAL RESOURCES OF KVICHAK BAY (CONT'D.)

AREA: Inner Bristol Bay
SUB-AREA: Naknek/Kvichak
SEASON:
HABITAT: Shallows and Intertidal
Sand and Gravel with Mud

SPECIES	ABUNDANCE BY SUB AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Lamprey *Entosphenus japonicus*	Low	Low	-	-	-	Med. to Low			Shallow Subtidal			Naknek River Estuary

BIOLOGICAL RESOURCES OF KVICHAK BAY (CONT'D.)

AREA Bristol Bay
SUB-AREA Central Bay
SEASON
HABITAT Bottom - Sand/Mud

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
General Sculpins[1] Cottidae	450 kg/ HR. Max. Trawl	Low	-	-	-	Med.		(Winter)		Adults	Amphipods Shrimp Brittlestars, etc.	Caught South of Cape Newenham
Saffron Cod *Eleginus gracilis*	70 kg/ HR. Max. Trawl		Low	-	-			December to February		Adults	Shrimp Amphipods Myside Polychaetes Ash Fry	
General Poachers Agonidae	65 kg/ HR. Max. Haul	Low	-	-	-	Low					Crustaceans	
General Skates Rajidae	35 kg/ HR. Max. Haul	Low	-	-	-	Low						
Pacific Sandfish *Trichodon trichodon*	35 kg/ HR. Max. Haul	Medium	-	-	-			Winter			Amphipods	
Starry Flounder[11] *Platichthys stellatus*	High	Low	-	Low	-	Med.		May to June	Winters in River Mouths Summers in Shallows	Adults	Polychaetes Shrimps Mollusks	Two Forms ? (Coastal and Marine)

BIOLOGICAL RESOURCES OF KVICHAK BAY (CONT'D.)

AREA: Bristol Bay
SUB-AREA: Central Bay
SEASON:
HABITAT: Bottom-Sand/Mud

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	LIFE HISTORY: SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Arrowtooth Flounder *Atheresthes stomias*	Low	Low	-	-	-	Low		April to May		Adults	Shrimps Fish - Herring Sandlance	
Pacific Halibut[12,13] *Hippoglossus stenolepis*	>270 kg HR.	Low	High	Low	Low	High		November to February	>80 m	Adults	Fish: Yellowfin Sole Pollock Sandlance	Primarily in area in June. Larvae often carried into shallow waters. Generally Bay fish are younger and smaller fish.
Pacific Halibut *Hippoglossus stenolepis*	-	High (when exposed)	-	-	-	High		Six to Seven-Month Period	Pelagic Mid-water to Surface	Eggs/Larvae		

BIOLOGICAL RESOURCES OF KVICHAK BAY (CONT'D.)

AREA Bristol Bay
SUB-AREA Inner Bay
SEASON
HABITAT Bottom - Sand

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Pink Shrimp [1, 14] *Pandalus borealis*	No Comm. Quar.		-	-	-	High		August to September Spawning	90 m or >	Adults		Large Diel Migration Migrate into Shallows to Breed.
								August to April Fem. Carry Eggs				Migrate into Shallows to Breed.
Pink Shrimp *Pandalus borealis*	No Comm. Quar.	High	-	-	-	High		February to May Hatch; February to July Free-swimming; May to July Settles to Bottom	Pelagic	Larvae		Migrate into Shallows to Breed.
Humpy Shrimp [15] *P. goniurus*	No Comm. Quan.		-	-	-	High			20 to 30 m for first two years then deeper			Cape Newenham Area
Rock Sole [11, 16] *Lepidopsetta bilineata*	Low to Medium	Low	Medium (Poten.)	-	-	Medium		February to May	Summer 40 to 20 m. Winter 80 to 60 m.	Adults		Don't Winter in Bay Migrate from Unimak Bank into Bay.

BIOLOGICAL RESOURCES OF KVICHAK BAY (CONT'D.)

AREA	Bristol Bay
SUB-AREA	Inner Bay
SEASON	
HABITAT	Bottom - Sand

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	LIFE HISTORY: SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Yellowfin Sole[11] *Limanda aspera*	Medium	Low	Low	-	-	High		June to August	Summer 0 to 120 m Winter 70 to 100 m	Adults	Shrimp Bivalve Mollusks Ophiuroids Amphipods	Special Concentration of fish <24 cm long Migration from Unimak Bank also.
Flathead Sole *Hippoglossoides elassodon*	Low	Low	Low	-	-	Low		February to March	Summer 0 to 160 m Winter 60 to 400 m	Adults	Ophiuroids Shrimps Amphipods Mollusks	Winter: Separate, large concentration over all of scope and lower part of shelf. Summer: Small, sparse concentration in shoal waters. Estimated at 36,000 metric ton yield.
Longhead Dab *Limanda proboscidea*	Low	Low	-	-	-	Low		July to August	Winter >100 m Summer 0 to 100 m	Adults		
Alaska Plaice *Pleuronectes quadrituberculatus*	Low	Low	-	-	-	Low		May to June	Winter >100 to 200 m Summer 0 to 100 m			Rare on Slope in Winter. Moves into shallows in Summer but does not form concentrations.

BIOLOGICAL RESOURCES OF KVICHAK BAY (CONT'D.)

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. Artic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, prepared for the Department of the Army, Alaska District, Corps of Engineers, February 1974.

2. Artic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, prepared for the Department of the Army, Alaska District, Corps of Engineers, February 1974.

3. Nelson, M., Alaska Dept. of Fish and Game, Personal Communication, (from source No. 1).

4. Haynes, E., and C. Lehman, eds., "Minutes of the Second Alaska Shellfish Conference," *ALASKA DEPT. OF FISH AND GAME INFORM. LEAFL. 135*, 1969.

5. Malick, J. G., S. L. Schroeder, and O. A. Mathisen, *OBSERVATIONS ON THE ECOLOGY OF THE ESTUARY OF NAKNEK RIVER, BRISTOL BAY, ALASKA*, University of Washington, Fisheries Research Institute, 1971.

6. Straty, R. R., "Ecology and Behavior of Juvenile Sockeye Salmon *(Onchorhynchus nerka)* in Bristol Bay and the Eastern Bering Sea," Chapter 14, *OCEANOGRAPHY OF THE BERING SEA WITH EMPHASIS ON RENEWABLE RESOURCES*, D. W. Hood and E. J. Kelley, eds., Univ. of Alaska, Institute of Marine Science, Occas. Pub. No. 2, 1974.

7. Shaboneev, I. E., "Biology and Fishing of Herring in the Eastern Part of the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART IV*, P. A. Moiseev, ed., Israel Program for Scientific Translation, 1965.

8. Musienko, L. N., "Reproduction and Development of Bering Sea Fishes," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translation, 1970.

9. Rumyantsev, A. I., and M. A. Darda, "Summer Herring in the Eastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

10. Malick, J. G., S. L. Schroeder, and O. A. Mathisen, *OBSERVATIONS ON THE ECOLOGY OF THE ESTUARY OF NAKNEK RIVER, BRISTOL BAY, ALASKA*, University of Washington, Fisheries Reserach Institute, 1971.

11. Fadeev, N. S., "Comparative Outline of the Biology of Flatfishes in the Southeastern Part of the Bering Sea and Conditions of Their Resources," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1965.

12. Novikov, N. P., "Basic Elements of the Biology of the Pacific Halibut, *Hippoglossus hippoglossus stenolepis* Schmidt, in the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

13. Shuntov, V. P., "Distribution of the Greenland Halibut and Arrow-toothed Halibuts in the North Pacific," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART IV*, P. A. Moiseev, ed., Israel Program for Scientific Translation, 1965.

14. Barr, L., and R. McBride, *SURFACE-TO-BOTTOM POT FISHING FOR PANDALID SHRIMP*, U. S. D. I. Fish and Wildlife Service Spec. Sci. Rept., Fisheries No. 560, 1967.

15. Neiman, A. A., "Quantitative Distribution of Benthos on the Shelf and Upper Continental Slope in the Eastern Part of the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART I*, P. A. Moiseev, ed., Israel Program for Scientific Translation, 1963.

16. Shubnikov, D. A., and L. A. Lisovenko, "Data on the Biology of the Rock Sole of the Southeastern Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translation, 1964.

KVICHAK BAY VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1, 2]	Beaches Streams Grass Flats	Population in Unit 9 perhaps rivals those anywhere in the world - population in this segment of low abundance, however.
Wolves and Wolverines[1]	Beaches Marsh Edges	Wolves low in numbers despite abundant food. Wolverines commonly seen on beaches. Average catch of wolverines is 36 annually.
Caribou[1]	Low Tundra	Estimated 12,000 to 15,000 on Peninsula. Wintering area east of Kvichak. Population increasing. Estimated 400 to 600 harvested per year.
Moose[1]	Willow Flats	There are an estimated 7,500 moose for Unit 9 with heaviest populations in the King Salmon—Meshik River areas. Annual kill 400 +. Important subsistence food item. Greatest population along rivers.
Aquatic Furbearers[2]	Nearshore Areas Beaches Marshes	River otter, mink, beaver and muskrats.
Harbor Seal[1]	Beaches Mud Flats	No population estimate. Apparently fair population. One local concentration area at Egikek Bay.
Bearded Seal[2]	Pack Ice Open Seas	Peripheral animals only during maximum south extent of pack ice.
Sea Lions[1]	Rocky Coves Beaches	Relatively low population. Rookery indicated on Walrus Island.
Walrus[2]	Rocky Beaches and Coves Nearshore Areas	Major haul-out ground on Walrus Island.
Whales[1]	River Mouths Open Sea	No population figures but known concentrations of beluga whales. Concentration in Bristol Bay heaviest May and first two weeks of June.
Ducks[1] Includes Sea Ducks	Nearshore Areas Beaches Estuaries Mud Flats	USFWS estimates 32 breeding ducks per square mile in Unit 9. Important migration area.
Geese[1]	Intertidal Areas Estuaries Near Sea	Important migration area for all species. Good production ur t but estimate not given.
Swans[1]	Intertidal Areas Estuaries	Two whistling swans per square mile. Important migration area.

KVICHAK BAY VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Seabirds[2]	Nearshore Seas	Migration area.
Shorebirds[2]	Beaches Mud Flats	Migration area.
Upland Game Birds[2]		
Raptors[2]		

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

CLIMATOLOGICAL SUMMARY

KING SALMON, ALASKA (King Salmon Airport) 58 41 N., 156 39 W. Elevation (ground) 44 feet WB-1961

Month	Air temperature (°F.) Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extreme: Record highest	Extreme: Record lowest	Precipitation (inches): Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	Humidity (percent): 8:00 a.m. Local time	2:00 p.m. Local time	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				19	19		19	12	8	8	6	6			6	6	6	6	16	12	6	6
Jan.	21.7	6.5	14.1	48	-39	1.05	0.87	6.6	78	77	9.8	N			6.9	7	6	18	10	3	0	2
Feb	25.4	10.5	18.0	51	-40	1.12	1.06	7.3	79	74	9.9	N			6.7	7	4	17	9	2	0	1
Mar.	29.3	13.3	21.3	56	-34	1.22	1.03	7.0	76	65	10.3	N			5.9	10	5	16	10	2	0	1
Apr.	41.2	25.0	33.1	65	-18	0.84	0.92	3.5	80	62	9.1	S			7.8	3	6	21	9	1	0	2
May	51.5	34.0	42.8	74	4	1.26	0.80	0.3	76	58	9.8	S			8.0	3	6	22	12	0	•	3
June	60.8	41.9	51.4	88	30	1.64	0.87	T	80	60	[illegible]	SSW			8.5	2	5	23	12	0	•	5
July	62.6	46.6	54.6	88	35	2.82	1.08	0.0	84	65	8.9	S			8.8	1	4	26	15	0	1	5
Aug.	61.8	47.4	54.6	82	31	4.01	1.45	0.0	88	67	[illegible]	S			8.7	1	6	24	19	0	0	3
Sep.	55.2	39.8	47.6	74	16	3.37	1.69	0.1	87	68	9.5	S			8.3	2	5	23	17	0	0	3
Oct.	42.6	29.0	35.8	67	-11	2.32	1.52	3.6	84	69	9.2	S			7.2	6	5	19	14	1	0	3
Nov.	28.8	15.2	22.1	50	-25	1.32	0.80	5.7	81	78	10.7	N			7.2	6	5	19	12	2	0	3
Dec.	21.8	6.6	14.2	48	-38	1.29	0.82	8.8	73	74	9.9	N			7.0	7	6	18	12	3	0	3
Year	41.8	26.3	34.1	88	-40	22.48	1.69	42.8	81	69	9.7	N			7.6	55	64	246	150	14	1	32

SOURCE: U. S. Department of Commerce and Coastal and Geodetic survey, *PACIFIC AND ARCTIC COASTS - ALASKA, CAPE SPENCER TO BEAUFORT SEA*, Seventh Edition (October 3, 1974), U. S. Coast Pilot Volume 9.

DATA PROCESSING DIVISION
ETAC/USAF
AIR WEATHER SERVICE/MAC

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND DIRECTION AND SPEED (FROM HOURLY OBSERVATIONS)

25503 (STATION) KING SALMON ALASKA APT (STATION NAME) 42-70 (YEARS) ALL (MONTH)

ALL WEATHER (CLASS) ALL (HOURS (L.S.T.))

CONDITION

SPEED (KNTS) DIR.	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥56	%	MEAN WIND SPEED
N	.5	2.2	3.7	3.3	1.3	.4	.1	.0				11.8	10.6
NNE	[illegible]	1.[illegible]	2.1	1.4	.5	.2	.0	.0				6.3	9.6
NE	[illegible]	1.[illegible]	1.3	.7	.3	.1	.0	.0	.0			4.6	8.3
ENE	[illegible]	[illegible]	1.0	[illegible]	.4	.2	.0	.0				3.7	10.1
E	.5	1.[illegible]	1.7	1.7	1.1	.4	.3	.1	.0	.[illegible]	.[illegible]	7.3	13.5
ESE	[illegible]	1.[illegible]	1.5	1.2	.7	.5	.2	.1	.0	.[illegible]		5.6	12.1
SE	[illegible]	1.[illegible]	1.6	.8	.4	.2	.1	.0	.0			5.2	9.2
SSE	[illegible]	1.5	1.7	1.2	.8	.5	.1	.0	.0	.0		6.5	11.2
S	[illegible]	[illegible]	2.2	1.7	.6	.2	.0	.0	.0			7.0	9.9
SSW	[illegible]	1.[illegible]	2.6	1.5	.4	.1	.0	.0	.0			5.5	9.2
SW	[illegible]	1.[illegible]	2.1	1.3	.2	.0	.0	.0				5.4	8.8
WSW	.4	[illegible]	1.4	1.1	.3	.1	.0	.0	.0			4.0	9.4
W	[illegible]	.5	1.2	.8	.2	.1	.0	.0				3.6	8.5
WNW	.4	[illegible]	1.0	.5	.1	.0	.0	.0				2.9	8.0
NW	[illegible]	1.[illegible]	1.2	.7	.2	.0	.0					3.5	8.2
NNW	[illegible]	1.4	2.1	1.7	.6	.2	.0	.0	.0			6.7	10.1
VARBL													
CALM												9.4	
	[illegible]	19.[illegible]	28.3	20.6	8.[illegible]	3.7	.9	.3	.1	.0	.0	100.0	9.1

TOTAL NUMBER OF OBSERVATIONS 215362

SOURCE: National Climatic Center, *SSMO (PART C)*.

USAFETAC FORM JUL 64 0-8-5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

ST. MATTHEW ISLAND: INFORMATIONAL RESOURCES

- St. Matthew Island Vicinity Salmonid Resources
- Fish and Shellfish Important at the St. Matthew Island Vicinity
- Biological Resources of the St. Matthew Island Vicinity
- St. Matthew Island Vicinity Mammals and Birds
- Surface Winds - Bering Sea

ST. MATTHEW ISLAND VICINITY SALMONID RESOURCES

The abundance and distribution of salmon in this area is not known. However, a safe speculation is that there are some salmon in the area most of the year. Bristol Bay sockeye and Yukon, Norton Sound, and Kotzebue Sound stock are in the general area as part of annual migration. The importance of these fish in relation to a spill is minimal since high seas salmon are very mobile and would probably avoid any polluted area. Salmon may not be present from about December to April when the island is surrounded by ice.

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. Straty, R. R., *ECOLOGY AND BEHAVIOR OF JUVENILE SOCKEYE SALMON (Oncorhynchus nerka) IN BRISTOL BAY AND THE EASTERN BERING SEA*. International Symposium for Bering Sea Study, Vol. 1, 1972.

2. Hartt, Allan C., *MOVEMENT OF SALMON IN THE NORTH PACIFIC OCEAN AND BERING SEA AS DETERMINED BY TAGGING, 1956-1958*, I.N.P.F.C. Bull. 6, 1972.

3. Royce, W. F., L. S. Smith, and A. C. Hartt, *MODELS OF OCEANIC MIGRATIONS OF PACIFIC SALMON AND COMMENTS ON GUIDANCE MECHANISMS*, U. S. Fish and Wildlife Service, Fishery Bull. 66(3):441-462, 1968.

FISH AND SHELLFISH IMPORTANT AT THE ST. MATTHEW ISLAND VICINITY

Flathead Sole
Yellowfin Sole - Most Important Flatfish
Rock Sole - Most Important Flatfish
Alaska Plaice
Herring
Pacific Halibut
Pacific Cod
Cottids
Tanner Crab
King Crab

KING CRAB

Not identified but presumed to be the northern or blue species. *(Paralithodes platypus)*.

HERRING

Probably most important commercial fishery. Supports a large foreign fleet and presumably there is some domestic fishing for roe herring also.

HALIBUT

In some years, substantial catches made close inshore, around the island in September and October. Few juvenile halibut were reported.

ALASKA PLAICE

Spawns immediately after the ice melts from early May to mid-June over the 100 m isoboth. Temperature from 0°C to 4°C.[2] Feeds on mollusks and polychartes.[3] Does not feed in Winter, all stomachs from a sample collected in February were empty.[4]

SOURCES:

1. Best, E. A., International Pacific Halibut Commission, Personal Communication.

2. Musienko, L. N., "Reproduction and Development of Bering Sea Fishes," *SOVIET FISHERIES INVESTIGATION IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

3. Skalkin, V. A., "Diet of Flatfishes in the Southeastern Bering Sea," *SOVIET FISHERIES INVESTIGATION IN THE NORTHEAST PACIFIC, PART I*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1963.

4. Mineva, T. A., "On the Biology of Some Flatfishes in the Eastern Bering Sea," *SOVIET FISHERIES INVESTIGATION IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

BIOLOGICAL RESOURCES OF THE ST. MATTHEW ISLAND VICINITY

AREA: Pribilofs - St. Matthew
SUB-AREA: Extrapolated to St. Matthew
SEASON:
HABITAT: Bottom - Rocky?

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	LIFE HISTORY: SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Pink Shrimp [1,2,3] *Pandalus borealis*	No Comm. Quant.	?	-	-	-	High		August to September Spawning August to April Fem. Carry Eggs February to May - hatch February to July - free-swimming	90 m or >	Adults Larvae		Large Diel migration. In Autumn migrate into shallows to breed.
Pacific Herring [4] *Clupea harengus pallasi*	High	Low to Medium	Med.	-	-	High			>100 m			Winter in dense schools on bottom northwest of Pribilofs. Leave area in March to April.
Pacific Ocean Perch [5] *Sebastes alutus*	Med.	Low	-	-	-	High		March to May	360 to 420 m	Larvae Juven.		Larvae expelled Southeast of Pribilofs.
Rock Sole [6, 7] *Lepidopsetta bilineata*	Med.	Low	-	-	-	Med.		February to May	Summer 40 to 120 m Winter 80 to 160 m.	Juven.	Polychaetes Mollusks Shrimp	Young fish winter on Pribilof Shelf.

BIOLOGICAL RESOURCES OF THE ST. MATTHEW ISLAND VICINITY (CONT'D.)

AREA: Pribilofs - St. Matthew
SUB-AREA: Extrapolated to St. Matthew
SEASON:
HABITAT: Bottom - Rocky?

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Yellowfin Sole *Limanda aspera*	Med.	Low	-	-	-	Low		June to August	Summer 40 to 120 m Winter 50 to 80 m	Juven.	Shrimp Bivalve Mollusks Ophiuroids Amphipods	Winter on lower part of Pribilof Shelf.
Flathead Sole *Hippoglossoides elassodon*	High	Low	Med.	-	-	Med.		February to May	Summer 40 to 150 m Winter 50 to 400 m	Adults	Ophiuroids Shrimps Amphipods Mollusks	Concentrated on shelf southwest of St. Matthew during Summer at North 190 m. Estimated 27-36,000 Metric Ton Yield.

BIOLOGICAL RESOURCES OF THE ST. MATTHEW ISLAND VICINITY (CONT'D.)

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. Artic Environmental Information and Data Center, *THE BRISTOL BAY ENVIRONMENT - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, prepared for the Department of the Army, Alaska District, Corps of Engineers, February 1974.

2a. Ivanov, B. G., "Some Data on the Biology of Shrimp in the Western Part of the Gulf of Alaska," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART I*, P. A. Moiseev, ed., Israel Program for Scientific Translation, 1963.

2b. Ivanov, B. G., *THE BIOLOGY AND DISTRIBUTION OF THE NORTHERN SHRIMP, Pandalus borealis KR., IN THE BERING SEA AND THE GULF OF ALASKA*, F.A.O. Fish Rept., 57(3):800-810, 1969.

3. Barr, L., and R. McBride, *SURFACE-TO-BOTTOM POT FISHING FOR PANDALID SHRIMP*, U.S.D.I. Fish and Wildl. Serv. Spec. Sci. Rept., Fisheries No. 560, 1967.

4. Dudnik, Y. I., and E. A. Usol'tsev, "The Herrings of the Eastern Part of the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART II*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1964.

5. Paraketsov, I. A., "On the Biology of *Sebastodes alutus* of the Bering Sea," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART I*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1963.

6. Alaska University, *COOK INLET ENVIRONMENT, A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, National Technical Information Service, U. S. Department of Commerce, COM-73-10337, August 1972.

7. Fadeev, N. S., "Comparative Outline of the Biology of Flatfishes in the Southeastern Part of the Bering Sea and Conditions of Their Resources," *SOVIET FISHERIES INVESTIGATIONS IN THE NORTHEAST PACIFIC, PART IV*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1965.

ST. MATTHEW ISLAND VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Polar Bear[1]	Pack Ice Beaches	Area coastal tundra. Southern limit of range, species currently protected but not endangered. Main impact is on food (seals in pack ice and grasses and sedges on land).
Polar Fox[1]	Pack Ice Beaches	Possible impact on food in pack ice, on beach foraging foods and on dens in beach areas.
Small Mammals[1]	Shore Tundra	Populations highly vaccillatory in abundances. Impact on foods and contact, if on shore.
Reindeer[1]	Shore Tundra	Unexploited wild herd - variously increases and declines. Main impact is possible disturbance.
Walrus[1]	Pack Ice Sea	Walrus herd variously migrates north and south, passing St. Matthews Island. Possible disturbance to migration. Food unlikely to be affected. Protected except to native people.
Northern Fur Seal[1]	Sea	Infrequent, transient animals only.
Ringed Seal[1]	Pack Ice	Protected from all except native people. Important part of their economy for food, skins, fuel, dog food.
Bearded Seal[1]	Pack Ice	As per walrus and ringed seal.
Harbor Seal[1]	Pack Ice Beaches	Year-long resident; possibly impacted most heavily in ice free months.
Ribbon Seal[1]	Pack Ice	St. Matthew northern range limit, mainly associated with pack edge in Winter, pelagic in Summer.
Whales[1]	Sea	Various species ranging from common minke and killer to rare and endangered forms.
Ducks[1]	Beaches Sea Grass Flats Estuaries	Possible major impact on nesting and overwintering sea ducks.
Geese[1]	Sea Estuaries Grass Flats	Mainly migrants.
Swans[1]	Estuaries Grass Flats	Not known positively but possible migration from and to Asia.

ST. MATTHEW ISLAND VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Seabirds[1]	Sea Estuaries	Heavy losses during feeding. Also displacement from feeding areas. Some disturbances and losses of nests in shore areas.
Shorebirds[1]	Beaches Estuaries	Possible food resources damaged; some onshore nesting.
Upland Game Birds[2]		
Raptors[2]		

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communications.

KUSKOKWIM - BERING SEA REGION - SURFACE WINDS

Station	Winter		Summer		Fastest Mile		2nd Fastest Mile	
	Prevailing Direction	Mean Speed (mph)	Prevailing Direction	Mean Speed (mph)	Direction	Speed (mph)	Direction	Speed (mph)
Akulurak	N		S; N					
Cape Romanzof	NE	13.5	SW; NE	9.5		55		47
St. Matthew Island	N; NE	15	SE; NW; SW	10	Several	>47		
Nunivak								
Bethel	NE; N	14	S; SW; NW	11.5	SE	62	SE	60
Akiak	N		N; S					

SOURCE: Swift, W. H., R. E. Brown, L. V. Kinnel, M. M. Orgel, P. L. Petersen, W. W. Waddell, *GEOGRAPHICAL ANALYSIS OF OIL SPILL POTENTIAL ASSOCIATED WITH ALASKAN OIL PRODUCTION AND TRANSPORTATION SYSTEMS*, Pacific Northwest Laboratory, Division of Memorial Institute to the United States Coast Guard, February 1974, Final Report No. CG-D-79-74.

NOME: INFORMATIONAL RESOURCES

- Nome Salmonid Resources
- Fish Important at Nome
- Biological Resources of Nome
- Nome Vicinity Mammals and Birds
- Climatological Summary - Nome
- Surface Winds - Nome

NOME SALMONID RESOURCES

Chum salmon are the most abundant in the commercial catches in the area from Cape Douglas to Stuart Island. The average catch (1965-1971) in thousands of fish are listed below:

Pink	38.50	(00.2 - 086.90)
Chum	75.00	(36.9 - 141.43)
Coho	04.50	(02.0 - 006.90)
King	01.80	(01.0 - 002.60)
Sockeye	<00.01	(00.0 - 000.01)

There is a substantial subsistence fishery in the Norton Sound area (does not include Yukon District). Average subsistence catches (1963-1971) are given below in thousands of fish.

King	00.50	(00.01 - 001.00)
Coho	02.70	(00.10 - 004.80)
Pink	18.80	(09.20 - 036.90)
Chum	19.70	(12.50 - 030.80)

The adult run timing is given below. The timing was estimated from weekly catch date of the fishery.

	Total Run	Peak
Pink Salmon	Mid-June - Early July	Mid-June
Chum Salmon	Late May - Late September	July-August
Coho Salmon	Mid-July - Mid September	Mid-August
King Salmon	Late May - Late August	Late June

The timing of juveniles is not known but they probably leave freshwater much later than the Bristol Bay fish due to cold water temperature and late ice breakup. The pink and chum salmon fry probably remain in the Norton Sound area through August, close to shore in estuarine conditions, for early feeding and growth.

NOME SALMONID RESOURCES (CONT'D.)

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. International North Pacific Fisheries Commission. Statistical Yearbook (for years stated).

2. State of Alaska, Department of Fish and Game, Arctic-Yukon-Kuskokwim (A-Y-K) Region Subsistence Fishery Report. Prepared by A-Y-K Staff, 1972.

3. U. S. Department of the Interior, *BERING SEA WILDERNESS STUDY AREA, BERING SEA NATIONAL WILDLIFE REFUGE, SECOND JUDICIAL DIVISION, ALASKA WILDERNESS STUDY REPORT*, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, 1966.

FISH IMPORTANT AT NOME

Herring
Coregonids
Osmerids
Pacific Cod
Saffron Cod
Cottids
Flathead Sole
Bering Flounder
Yellowfin Sole
Longhead Dab
Arctic Flounder
Starry Flounder

ARCTIC FLOUNDER

The Arctic flounder spawns from January through March. Spawning takes place nearshore under the ice at a depth of 5 to 10 m and at temperatures of $-1^{o}C$.[2]

SOURCES:

1. Best, E. A., International Pacific Halibut Commission, Personal Communication.

2. Musienko, L. N., "Reproduction and Development of Bering Sea Fishes," *SOVIET FISHERIES INVESTIGATION IN THE NORTHEAST PACIFIC, PART V*, P. A. Moiseev, ed., Israel Program for Scientific Translations, 1970.

BIOLOGICAL RESOURCES OF NOME

AREA: Nome
SUB-AREA: Norton Sound
SEASON: All Year
HABITAT: Bottom - Sand/Mud?

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Saffron Cod [1,2] *Eleginus gracilis*	Common	Low	Potential	Low	-	Medium	-	December to February	60 m and <	Adult	Shrimp Amphipods Mysids Polychaetes Fish Fry	Approaches shallows in Winter for Spawning. In Summer migrates deeper 30 to 60 m to feed. Spawns in deeper parts of Norton Sound on pebbly bottom.

BIOLOGICAL RESOURCES OF NOME (CONT'D.)

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. Andriashev, A. P., *FISHES OF THE NORTHERN SEAS OF THE USSR*, Israel Program for Scientific Translations, 1954.

2. Turner, L. M., *CONTRIBUTIONS TO THE NATURAL HISTORY OF ALASKA*, Army Signal Service, Arctic Series Publ. 2, 226 pp., 1886.

NOME VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1, 2]	Beaches and Low Tundra	Few population data available. Sparse abundance with minor concentrations where berries or salmon available. Reported harvest 2 to 5 since 1961.
Polar Bear[1, 2]	Pack Ice	Very few in Norton Sound - minor occurrence during Winter - retreat with ice.
Polar Fox[2]	Pack Ice and Beaches	
Wolf and Wolverine[1, 2]	Beaches and Nearshore Tundra	Wolverine population low but increasing. Population controlled in past. Harvest 4 to 31 since 1961-1962, high 1966 to 1968 period. Wolf population low due to control related to reindeer herding. Kills 6 to 28 yearly since 1962-1963, high 1967-1968.
Moose[1, 2]	Willow Flats	Common on Seward Peninsula only since 1950's. First record Cape of Wales 1948. Still expanding and increasing - Unit harvest 35 to 72 in recent years. Habitat limited to willow flats along streams.
Muskox[1]	Beaches and Nearshore Tundra	1970 - 36 introduced to Feather River near Nome. Currently three groups. One near Cape Rodney - calf crops not encouraging - spill could result in local population loss.
Caribou[1]	Nearshore Tundra	Caribou present in low numbers. Difficult to separate from reindeer (interbreed). Entire coastal plain is a summering area.
Bearded Seal[1]	Pack Ice Open Seas	Major Spring and wintering areas on pack ice of Game Units 18 and 22. Migrate north with walrus but do not concentrate. Some young spend Summers in Bering Sea.
Harbor Seal[1]	Pack Ice Beaches Open Seas	March and April concentrate along southern margin of sea ice where they bear young.
Ribbon Seal[1]	Pack Ice Open Seas	Mainly confined to Bering Sea year-round. Seldom nearshore - few migrate north through Bering Strait mainly along ice edge in late Winter and early Spring. Remain in open sea during ice-free period.
Walrus[1]	Pack Ice	Begin north migration in mid-April with ice breakup. Reach Bering Strait by last week of May. A few males remain in Bering Sea during Summer and occupy beaches and islands. A number of haulout areas in Unit 22. Population increasing. Haulout area on Sledge Island.

NOME VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Ringed Seal[1]	Inshore Fast Ice	Migrates with ice. Part of population remains in ice-free areas. Most adults occupy land-fast ice. Most abundant of Arctic seals and of greatest importance to natives. Migrations near shore.
Whales[1]	Open Seas	Sixteen species in waters of Bering Sea. Primarily in open waters (list of species); follow ice movements sometimes into pack.
Ducks[1]	Open Seas Beach Flats Estuaries	Sixty ducks per square mile - Unit population of 231,000 breeders contributes production of 416,000 young. Greater scaup and pintails most common species. Coastal lagoons contain fine stands of eel grass important to wildlife.
Geese[1]	Open Seas Beach Flats Beaches Estuaries	Few emporer, white-fronted and brant. Native hunting thought to have decreased goose population.
Seabirds[1]	Inshore Areas Beaches	Bird colonly on Sledge Island - good comment on concern of disturbance by aircraft.
Shorebirds[2]	Beaches Tide Flats	
Upland Game Birds[2]		
Raptors[2]		

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

CLIMATOLOGICAL SUMMARY

NOME, ALASKA (Nome Field). 64°30'N., 165°26'W., Elevation (ground) 13 feet WB-1961

Month	Air temperature (°F.) Normal* Daily maximum	Daily minimum	Monthly	Extreme Record highest	Record lowest	Precipitation (inches) Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	Humidity (percent) 7:00 a.m. Local time	1:00 p.m. Local time	Wind (knots) Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				15	15		15	15	15	15	14	13		13	15	15	15	15	15	15	15	15
Jan.	12.8	-1.7	5.6	38	-38	1.23	0.78	11.6	78	77	10.1	E		43	6.3	8	6	18	11	4	0	3
Feb.	13.6	-2.2	5.7	47	-43	0.83	0.52	8.2	75	74	10.3	NE		49	6.4	11	5	13	9	3	0	1
Mar.	16.8	0.1	8.5	42	-38	0.61	0.65	8.8	78	73	9.1	E		50	6.0	10	5	16	10	3	0	1
Apr.	28.7	13.3	21.0	51	-27	0.78	0.58	7.3	80	77	9.1	E		53	6.6	8	6	16	10	2	0	1
May	40.5	26.8	33.7	68	-11	0.56	0.70	1.4	78	73	9.0	N		48	6.7	7	8	16	8	*	0	3
June	53.0	38.4	45.8	81	25	1.08	2.02	0.1	81	77	9.3	WSW		37	7.3	4	8	17	8	0	*	2
July	55.4	43.8	49.8	80	32	2.48	1.77	0.0	87	83	8.5	WSW		30	8.1	3	7	22	13	0	*	3
Aug.	55.0	43.2	49.1	73	30	3.76	2.38	T	88	83	8.1	SW		30	8.3	3	5	24	16	0	*	3
Sep.	48.1	35.6	42.0	63	17	2.83	1.38	0.8	85	78	10.1	N		39	7.8	4	5	21	14	*	0	*
Oct.	35.7	24.2	30.0	58	-3	1.70	2.28	5.1	81	74	9.6	N		34	7.8	4	5	19	9	2	0	*
Nov.	22.8	10.8	16.8	44	-38	1.14	0.48	10.7	82	81	11.1	N		38	7.2	5	5	20	13	3	0	1
Dec.	14.3	1.1	7.7	38	-41	1.16	1.09	8.5	76	76	8.9	E		33	6.5	10	4	17	8	3	0	3
Year	33.1	19.5	26.3	81	-43	18.89	2.38	60.5	81	77	9.5	N		38	6.9	79	69	217	131	30	*	23

SOURCE: U. S. Department of Commerce and Coastal and Geodetic survey, *PACIFIC AND ARCTIC COASTS - ALASKA, CAPE SPENCER TO BEAUFORT SEA*, Seventh Edition (October 3, 1974), U. S. Coast Pilot Volume 9.

NORTON SOUND - SURFACE WINDS

Station	Winter		Summer		Fastest Mile		2nd Fastest Mile	
	Prevailing Direction	Mean Speed (mph)	Prevailing Direction	Mean Speed (mph)	Direction	Speed (mph)	Direction	Speed (mph)
Teller	N; E		N; W; S					
Port Clarence								
Nome	N; E	11	SW; N	10.5	SW	55	NE; E	54
White Mountain	N; NW		NW; SW; SE					
Moses Point	N; NE	13	SW; S	13	N	>65	Several	>55
Koyuk	NE; N; NW	12	S; SW	13	Several	>47		
Unalakleet	NE	16	NE; W	11	NE	56	SE	53
St. Michael	N; NE		N; NW; SW					
Northeast Cape								
Savoonga	N; NE		NE; N; NW					
Gambell	NE		NE; N; SW					

SOURCE: Swift, W. H., R. E. Brown, L. V. Kinnel, M. M. Orgel, P. L. Petersen, W. W. Waddell, *GEOGRAPHICAL ANALYSIS OF OIL SPILL POTENTIAL ASSOCIATED WITH ALASKAN OIL PRODUCTION AND TRANSPORTATION SYSTEMS*, Pacific Northwest Laboratory, Division of Memorial Institute to the United States Coast Guard, February 1974, Final Report No. CG-D-79-74.

DATA PROCESSING DIVISION
ETAC/USAF
AIR WEATHER SERVICE/MAC

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND
DIRECTION AND SPEED
(FROM HOURLY OBSERVATIONS)

25517 [illegible] APT — STATION / STATION NAME
45-70 — YEARS
ALL — MONTH
ALL WEATHER — CLASS
ALL — HOURS (L.S.T.)
CONDITION

SPEED (KNTS) DIR	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥56	%	MEAN WIND SPEED
N	2.0	2.[illegible]	2.8	2.[illegible]	.5	.2	.0	.0	.0			10.4	8.2
NNE	.9	1.2	1.4	1.[illegible]	.8	.4	.1	.0	.0	.0		6.4	10.9
NE	1.[illegible]	1.4	2.0	2.[illegible]	1.1	.5	.2	.0	.0			9.0	11.5
ENE	.5	.9	1.9	2.[illegible]	1.3	.8	.2	.0	.0			6.5	13.[illegible]
E	.9	1.3	2.4	2.5	1.6	1.0	.3	.1	.0	.0	.0	10.6	13.0
ESE	.4	.[illegible]	1.2	1.4	.6	.4	.1	.0	.0	.0		5.0	11.6
SE	.5	.[illegible]	1.3	1.2	.4	.2	.0	.0	.0			4.5	10.3
SSE	.4	.7	1.0	.8	.4	.2	.1	.0	.0	.0		3.4	11.0
S	.[illegible]	1.0	1.1	.9	.3	.2	.0	.0	.0	.0		4.1	9.8
SSW	.6	.[illegible]	.7	.7	.3	.1	.0	.0	.0	.0		2.9	10.[illegible]
SW	.9	1.1	1.6	1.[illegible]	.4	.2	.1	.0	.0			4.0	9.[illegible]
WSW	.3	.5	1.6	1.3	.4	.1	.0	.0	.0			4.5	10.2
W	.[illegible]	.9	1.4	1.2	.3	.1	.0	.0				4.5	9.5
WNW	.[illegible]	1.0	1.0	.8	.2	.1	.0	.0	.0			3.6	8.7
NW	1.4	1.7	1.3	.7	.3	.1	.0	.0				5.4	7.6
NNW	1.0	1.7	1.4	.7	.2	.1	.0	.0	.0			5.1	7.3
VARBL													
CALM												7.5	
	11.7	14.7	24.3	22.7	9.0	4.6	1.2	.3	.1	.0	.0	100.0	9.6

TOTAL NUMBER OF OBSERVATIONS 190665

SOURCE: National Climatic Center, *SSMC (PART C)*.

CAPE BLOSSOM (KOTZEBUE): INFORMATIONAL RESOURCES

- Cape Blossom Salmonid Resources
- Fish Important at Cape Blossom
- Biological Resources at Cape Blossom
- Cape Blossom Vicinity Mammals and Birds
- Climatological Summary - Kotzebue
- Surface Winds - Kotzebue Sound
- Surcace Winds - Kotzebue
- Surface Wind Speed - Cape Thompson versus Kotzebue

CAPE BLOSSOM SALMONID RESOURCES

The only major commercial salmon fishery is on chum salmon. The mean actual catch (1965-1971) is 72,000. The Noatak and Kobuk rivers are the major producers and are in the vicinity of the spill site. Smolts and juveniles would be in this area throughout the summer. There is also a substantial subsistence fishery in the two rivers that harvests 20 - 70,000 chums annually. Approximately 10 - 30,000 sheefish are caught for subsistence annually. They are anadromous and present in the Hotham Inlet area in the early spring. They move into the rivers in the late summer to spawn.

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. International North Pacific Fisheries Commission. Statistical Yearbook (for the years stated).

2. State of Alaska, Department of Law, *COMMENTS ON THE PROPOSED TRANS-ALASKA PIPELINE*, July 30, 1971.

3. Anonymous. *FISHERY STATUS REPORT, NORTHERN REGION, YUKON AREA*, ADF&G, Region III, Fairbanks.

4. Wilimovsky, Norman J. (Editor) and John N. Wolfe (Associate Editor), *ENVIRONMENT OF THE CAPE THOMPSON REGION, ALASKA*, Atomic Energy Commission, Report PNE-481, 1966.

FISH IMPORTANT AT CAPE BLOSSOM

Marine Fish species are thought to be about the same as at Nome.

Cape Thompson investigators (study primarily of Chukchi Sea northwest of Kotzebue report the following:

LIST OF MARINE AND FRESHWATER FISHES TAKEN DURING CHUKCHI SEA INVESTIGATION

MARINE FISHES

Clupea harengus pallasi
Onchorhynchus gorbuscha
Oncorhynchus keta
Salvelinus alpinus
Salvelinus malma
Osmerus dentex
Mallotus villosus
Eleginus gracilis
Boregadus saida
Atheresthes stomias
Hippoglossoides robustus
Limanda aspera
Pleuronectes quadrituberculatus
Liopsetta glacialis
Platichtys stellatus
Hexagrammos stelleri
Hemilepidotus sp.
Icelius s. spatula
Triglops pingeli
Artediellus scaber beringianus
Megalocottus platycephalus
Myoxocephalus scorpius
Myoxocephalus sp.
Myoxocephalus jaok
Myoxocephalus stelleri
Myoxocephalus quadricornis
Microcottus sellaris
Gymnocanthus tricuspis orientalis
Enophris lucasi
Nautichthys pribilovius
Aspidophoroides olriki
Podothecus acipenserinus
Liparis herschelinus
Liparis sp.
Ammodytes hexapterus
Stichaeus punctatus
Fumesogrammus praecisus
Lumpenus fabricii
Lumpenus mediums
Lyocedes palearis acticus
Lyocedes raridens
Lycodes sp.
Gymnelis viridis

FRESHWATER FISHES

Salvelinus malma
Salvelinus alpinus
Coregonus autumnalis
Coregonus sardinella
Coregonus laveratus pidschian
Thymallus arcticus
Cottus cognatus
Gasterosteus aculeatus
Pungitius pungitius

FISH IMPORTANT AT CAPE BLOSSOM (CONT'D.)

The field data give some order of abundance of the different species. Numerically, the ten dominant marine forms within the area of our exploration of the Chukchi Sea are

Boreogadus saida
Clupea harengus pallasi
Gymnocanthus tricuspis
Artediellus scaber
Mallotus villosus
Hippoglossoides robustus
Osmerux dentex
Myoxocephalus scorpius
Triglops pingeli
Eleginus gracilis

By frequency of occurrence within the station pattern, the ten dominant marine forms are:

Boreogadus saida
Gymnocanthus tricuspis
Hippoglossoides robustus
Myoxocephalus scorpius
Triglops pingeli
Podothecus acipenserinus
Lunpenus fabricii
Artediellus scaber
Osmerus dentex
Lycodes sp.

Bering flounder, most numerous of the flounders, reported by Pruter and Alverson. They thought that spawning did not occur north of Bering Strait and the larvae drifted in with the current.

SOURCES:

1. Best, E. A., International Pacific Halibut Commission, Personal Communication, 1974.

2. Wilimovsky, Norman J. (Editor) and John N. Wolfe (Associate Editor), *ENVIRONMENT OF THE CAPE THOMPSON REGION, ALASKA*, Atomic Energy Commission Report PNE-148, 1966.

3. Pruter, Alonzo T. and Dayton L. Alverson, *ABUNDANCE, DISTRIBUTION, AND GROWTH OF FLOUNDERS IN THE SOUTHEASTERN CHUKCHI SEA*, 1962.

BIOLOGICAL RESOURCES OF CAPE BLOSSOM

AREA Cape Lisburne - Kotzebue Sound
SUB-AREA Cape Thompson
SEASON Summer
HABITAT Hard (Rock, Gravel Bottom)

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	IMPORTANCE: ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Arctic Cod [1] *Boreogadus saida*	High			High					Bottom	Adults		
Pacific Herring *Clupea harengus pallasi*	High			-					Pelagic	Adults		
Arctic Staghorn Sculpin *Gymnocanthus tricuspis*	High			-					Bottom	Adults		
Hamecon Sculpin *Artediellus scaber*	Common			-						Adults		
Capelin Smelt *Mallotus villosus*	Common			-					Pelagic	Adults		
Bering Flounder *Hippoglossoides robustus*	Common			-					Pelagic	Adults		
Rainbow Smelt *Osmerus eperlanus*	Common								Bottom	Adults		

BIOLOGICAL RESOURCES OF CAPE BLOSSOM (CONT'D.)

AREA Cape Lisburne Kotzebue Sound
SUB-AREA Cape Thompson
SEASON Summer
HABITAT Hard (Rock, Gravel Bottom)

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	IMPORTANCE: ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Shorthorn Sculpin *Myoxocephalus scorpius*	Common			-					Bottom	Adults		
Ribbed Sculpin *Triglops pingeli*	Common			-					Bottom	Adults		
Saffron Cod *Eleginus gracilis*	Common			Low					Bottom	Adults		

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. Wilimovsky, Norman J. (Editor) and John N. Wolfe (Associate editor), *ENVIRONMENT OF THE CAPE THOMPSON REGION, ALASKA*, Atomic Energy Commission, Report PNE-481, 1966.

CAPE BLOSSOM VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1, 2]	Beaches Grass Flats	Sparse to medium population. No precise estimates. Important native food item. Concentrations on streams.
Polar Bear[1, 2]	Pack Ice	Few polar bear enter Sound. Heavy ice years may result in greater population occurrences.
Polar Fox[2]	Pack Ice Beaches	Low populations believed to occur in the area, although little known.
Wolves and Wolverines[1]	Beaches	Wolves - modest population dependent on caribou. Number of kills 71 to 177 since 1961 to 1962, higher 1967 to 1968. Wolverines modest population; kills 2 to 51 since 1961 to 1962, higher 1963 to 1964.
Caribou[1]	Nearshore Tundra Areas	Part of large Arctic herd of over 240,000.
Moose[1]	Willow Flats	Population expanding into the area. Important local source of food. Harvests estimated at 100 to 150 per year.
Ringed Seals[2]	Pack Ice	Moderate populations coincide with presence of pack ice. Some animals remain in area during ice-free period.
Harbor Seals[2]	Pack Ice	Moderate populations inshore areas during ice-free period. Major population component present along edge at all seasons.
Bearded Seals[2]	Pack Ice	Sparse abundance in area during pack ice period.
Ribbon Seals[2]	Pack Ice	Year-long residents of Bering Sea. Pelagic during Summer and along pack edge during Winter.
Northern Fur Seals[2]	Pack Ice	Transient occurrence during ice-free period.
Walrus[2]	Pack Ice Open Seas	For the most part the walruses migrating through Bering Sea pass to the west of Cape Blossom. Possible occurrences in the vicinity with favorable ice conditions.
Whales[2]	Open Seas	Possible occurrences of several species during the ice-free period -- mainly beluga and killer whales. Less frequently bowhead whales.
Ducks[1, 2]	Beaches Estuaries	One of the most productive waterfowl units in State. Average 44 breeding ducks per square mile. $\bar{x}$ average production by the 224,000 breeding ducks, 187,000 young.

CAPE BLOSSOM VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Geese[1]	Beaches Marshes	Concentrations of Canada and white-fronted geese.
Shorebirds[2]	Beaches Tideflats	Major breeding populations of shorebirds likely. Also large numbers of migrants.
Seabirds[2]	Inshore Areas	A number of seabird colonies at the base of the Sound. Significant population of kittiwakes, murres, gulls, and puffins in the area.

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

CLIMATOLOGICAL SUMMARY

KOTZEBUE, ALASKA (Federal Aviation Agency Airport) 66°52'N, 162°38'W, Elevation (ground) 10 feet WB-1961

Month	Air temperature (°F.) Normal: Daily maximum	Daily minimum	Monthly	Extreme: Record highest	Record lowest	Precipitation (inches): Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	Humidity (percent): 7:00 a.m. Local time	1:00 p.m. Local time	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover, sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				19	19		13	18	18	18	17	18			18	18	18	18	18	18	11	18
Jan	6.6	-13.7	[illegible]	3[illegible]	-47	[illegible]	0.24	5.3	71	71	[illegible]	E			5.8	11	5	15	8	2	0	1
Feb	2.5	-11.2	-4.2	37	-53	[illegible]	[illegible]	4.6	72	73	[illegible]	E			5.3	11	4	13	8	1	0	1
Mar	6.6	-9.7	-1.6	38	-48	[illegible]	[illegible]	5.3	73	73	[illegible]	E			5.6	11	6	14	8	2	0	1
Apr	22.2	5.2	13.8	46	-44	[illegible]	0.29	4.1	75	77	[illegible]	ESE			5.8	10	7	13	7	2	0	2
May	36.3	22.8	29.6	74	-18	[illegible]	[illegible]	1.0	84	[illegible]	[illegible]	W			6.5	7	9	15	7	*	0	4
June	49.2	37.[illegible]	43.3	81	20	[illegible]	[illegible]	0.1	85	81	[illegible]	W			7.0	5	9	16	7	0	0	5
July	58.5	46.7	52.6	85	34	1.5[illegible]	1.78	T	88	[illegible]	[illegible]	W			7.7	3	7	21	11	0	*	3
Aug	55.8	[illegible]	[illegible]	72	31	[illegible]	1.49	T	[illegible]	[illegible]	[illegible]	W			8.3	2	5	24	15	0	*	1
Sep	45.6	35.[illegible]	40.5	61	17	[illegible]	[illegible]	1.0	88	77	[illegible]	E			7.8	5	5	20	13	*	0	1
Oct	30.2	20.7	25.5	51	-9	[illegible]	[illegible]	5.6	87	78	[illegible]	ENE			7.1	7	5	19	14	2	0	1
Nov	12.9	2.1	7.5	38	-36	[illegible]	[illegible]	7.5	77	[illegible]	[illegible]	E			6.7	7	5	15	10	3	0	1
Dec	3.3	[illegible]	-3.7	36	-47	[illegible]	[illegible]	6.2	72	72	[illegible]	E			6.0	10	5	16	9	2	0	1
Year	27.0	[illegible]	[illegible]	[illegible]	48	[illegible]	1.78	[illegible]	80	[illegible]	[illegible]	E			6.6	89	72	204	112	12	*	21

SOURCE: U. S. Department of Commerce and Coastal and Geodetic survey, *PACIFIC AND ARCTIC COASTS - ALASKA, CAPE SPENCER TO BEAUFORT SEA*, Seventh Edition (October 3, 1974), U. S. Coast Pilot Volume 9.

KOTZEBUE SOUND - SURFACE WINDS

Station	Winter		Summer		Fastest Mile		2nd Fastest Mile	
	Prevailing Direction	Mean Speed (mph)	Prevailing Direction	Mean Speed (mph)	Direction	Speed (mph)	Direction	Speed (mph)
Kotzebue	E;SE;NE	13	W	13	SE	93	SE	88
Noorvik	E		W;E					
Candle	N;NW		N;SE					
Shishmaref	N;NW		N;NW;S					
Wales/Tin City	N;NE	20	N;S;SE	15	NW	>65	Several	63

SOURCE: Swift, W. H., R. E. Brown, L. V. Kinnel, M. M. Orgel, P. L. Petersen, W. W. Waddell, *GEOGRAPHICAL ANALYSIS OF OIL SPILL POTENTIAL ASSOCIATED WITH ALASKAN OIL PRODUCTION AND TRANSPORTATION SYSTEMS*, Pacific Northwest Laboratory, Division of Memorial Institute to the United States Coast Guard, February 1974, Final Report No. CG-D-79-74.

DATA PROCESSING DIVISION
ETAC/USAF
AIR WEATHER SERVICE/MAC

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND
DIRECTION AND SPEED
(FROM HOURLY OBSERVATIONS)

26616 (STATION) KOTZEBUE ALASKA/RALPH WIEN APT (STATION NAME) 45-70 (YEARS) ALL (MONTH)

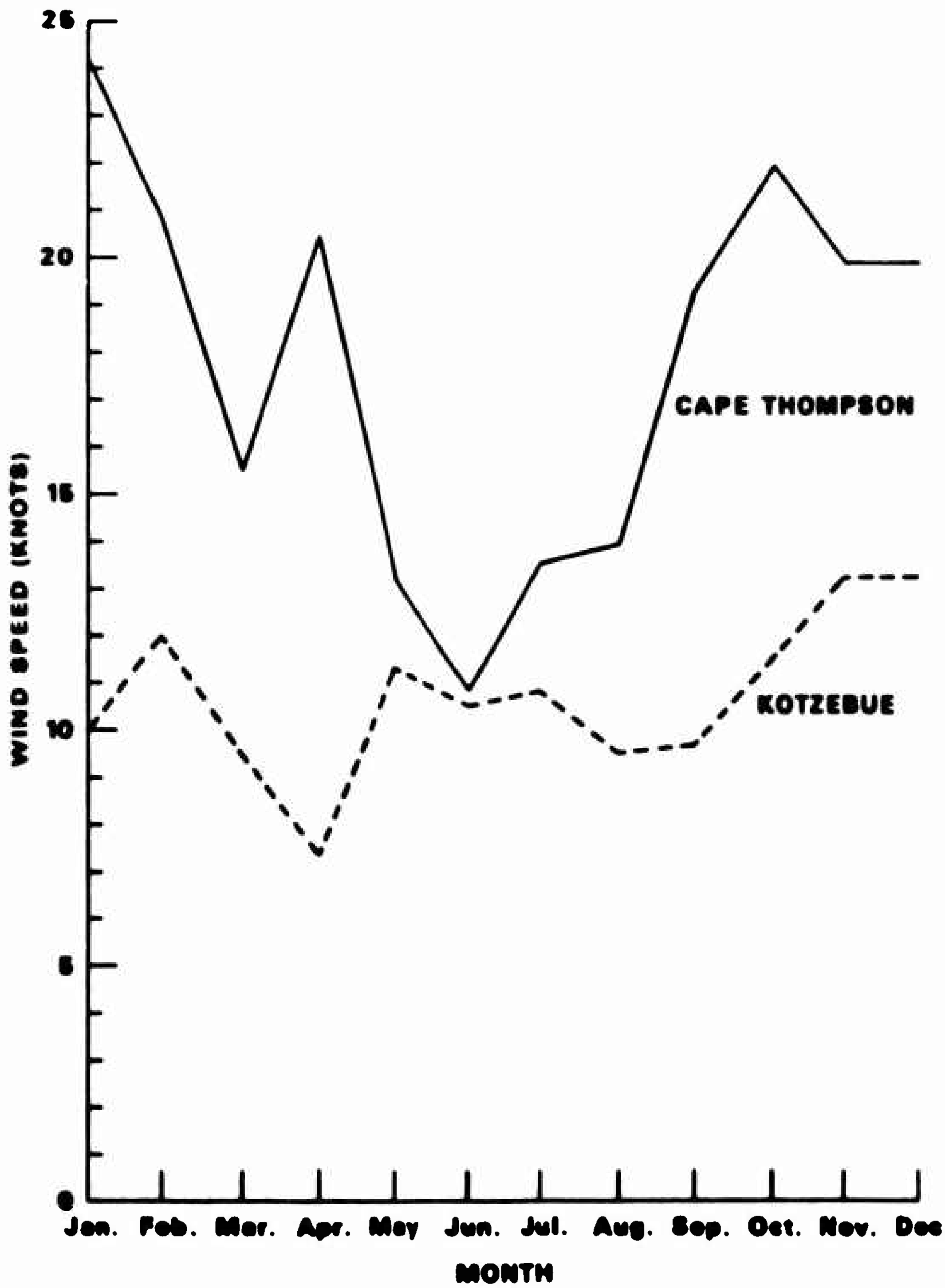
ALL WEATHER (CLASS) ALL (HOURS (L.S.T.))

(CONDITION)

SPEED (KNTS) DIR	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥ 56	%	MEAN WIND SPEED
N	.5	1.2	1.8	1.3	.4	.1	.0	.0				5.4	9.4
NNE	.6	1.7	2.2	.5	[illegible]	.0	.0					5.0	7.1
NE	.9	2.8	2.8	.6	.1	.0	.0	.0	.0			7.3	7.0
ENE	.8	2.4	2.5	1.4	.5	.2	.1	.0	.0			8.0	8.9
E	.8	1.6	2.5	3.2	1.9	1.3	.6	.2	.1	.0		12.2	14.0
ESE	.5	1.1	2.3	3.8	2.4	1.9	.7	.3	.1	.0	.0	13.0	15.7
SE	.3	.6	1.2	1.6	.8	.4	.1	.0	.0	.0		5.1	12.7
SSE	.2	.4	.7	.9	.5	.2	.1	.0	.0	.0		3.0	12.3
S	.3	.6	.8	.8	.3	.1	.0	.0				2.8	10.4
SSW	.2	.6	.8	.4	.1	.1	.0	.0	.0	.0	.0	2.2	9.1
SW	.4	1.0	1.2	.7	.2	.1	.0	.0	.0	.0	.0	3.7	9.1
WSW	.4	1.0	1.5	1.2	.4	.2	.0	.0		.0		4.7	10.1
W	.3	1.2	2.3	2.9	1.3	.5	.1	.0	.0	.0		8.8	12.1
WNW	.4	1.0	2.0	2.6	1.3	.7	.1	.0	.0	.0	.0	8.7	13.1
NW	.3	.7	1.0	1.0	.4	.2	.0	.0	.0			3.7	11.1
NNW	.4	.7	.8	.9	.4	.2	.0	.0				3.4	10.7
VARBL													
CALM												3.0	
	7.5	18.8	26.3	24.0	11.2	6.6	2.0	.7	.1	.0	.0	100.0	11.1

TOTAL NUMBER OF OBSERVATIONS 192368

SOURCE: National Climatic Center, SSMO (PART C).



COMPARISON OF 1960 MEAN MONTHLY WIND SPEED (IN KNOTS) BETWEEN KOTZEBUE AND CAPE THOMPSON, OGOTORUK CREEK (AFTER ALLEN AND WEEDFALL, 1966).

SOURCE: Alaska Planning Group, *ENVIRONMENTAL STATEMENT-PROPOSED CAPE KRUSENSTERN NATIONAL MONUMENT, ALASKA*, National Park Service, U. S. Department of the Interior, DES 73 87, December 1973, Draft.

OFFSHORE PRUDHOE: INFORMATIONAL RESOURCES

- Offshore Prudhoe, Inshore Prudhoe, Inshore Umiat (Colville Delta) Salmonid Resources
- Fish Important at Prudhoe Bay
- Biological Resources at Offshore Prudhoe Vicinity
- Offshore Prudhoe Vicinity Mammals and Birds
- Climatological Summaries for Barrow and Barter Island
- Surface Winds - North Slope
- Surface Winds - Barter Island

OFFSHORE PRUDHOE, INSHORE PRUDHOE
INSHORE UMIAT (COLVILLE DELTA) SALMONID RESOURCES

There is no commercial fishery on salmonids in the Beaufort Sea. The importance of salmon for subsistence of the local inhabitants is also limited. Sport fishing is only potential at this time. Chum and pink salmon are present in the river systems but their abundances are unknown (to me). They spawn in the all and migrate out, probably in June when the ice is free. Rainbow smelt are also anadromous and spawn in the rivers. Other salmonids in the area are Arctic char, sheefish, whitefish (three species), cisco (three species), grayling and lake trout. All are Fall spawners except the grayling which is a Spring spawner. Some of the Arctic char Winter in the estuaries of river deltas but are not actually anadromous.

* Note: Perhaps since there are no significant fisheries in the area some score should be given for general productivity. It should be low.

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW.

1. State of Alaska, Department of Law, *COMMENTS ON THE PROPOSED TRANS-ALASKA PIPELINE*, July 30, 1971.

2. State of Alaska, Department of Fish and Game, Arctic-Yukon-Kuskokwim (A-Y-K) Region Subsistence Fishery Report, Manuscript prepared by A-Y-K Staff, 1972.

3. The Arctic Institute of North America, *THE ALASKAN ARCTIC COAST - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, Contract No. DACW85-74-C-0029, June, 1974.

FISH IMPORTANT AT PRUDHOE BAY [1]

Herring
Corogonids
Sandlance
Osmerids (Smelt)
Navaga (Cod)
Saffron Cod
Cottids (Sculpins)
Liparids (Lumpfish)
Artic Flounder
Starry Flounder

CAPELIN *(Mollotus villosus)*

A smelt, reported spawning on the beaches at Pt. Barrow in late July and early August.[2] Eggs are demersal and attach to the bottom gravel, hatch in 55 days at 0°C. Newly hatched larvae are pelagic near surface until Winter cooling sets in.

Capelin are filter feeders. Euphasids were the highest proportion of food items by weight, but copepods occured more frequently.[3]

SOURCES:

1. Best, E. A., International Pacific Halibut Commission, Personal Communication.

2. Walters, V., "Fishes of Western Arctic America and Eastern Arctic Siberia, Taxonomy and Zoogeography," *AM. MUS. NAT. HIST. BULL.*, 106(5):255-368, 1955.

3. Jangaard, P. M., "The Capelin *(Mallotus villosus)* Biology, Distribution, Exploitation, Utilization and Composition," *FISH. RES. BD. CANADA*, Bulletin 186:70 p., 1974.

BIOLOGICAL RESOURCES OF OFFSHORE PRUDHOE VICINITY

AREA: Arctic Prudhoe
SUB-AREA: Cape Thompson
SEASON: Summer Primarily
HABITAT: Estuarine - Soft Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Arctic Flounder [1,2]	Common	Low							Bottom	Adult		
Starry Flounder *Platichthys stellatus*	Common	Low	Low	Low	-	Medium			Bottom	Adult		Conc. in Estuaries
Fourhorn Sculpin *Myoxocephalus quadricornis*	Common	Low	-	-	-	Low		Summer	Shallow	Adult		Spawns Inshore
Ribbed Sculpin [3] *Triglops pingeli*	Common	Low	-	-	-	Low				Adult		Tolerates higher salinities
Arctic Cod [4] *Boreogadus saida*	Common	Low	Low	High	-	High			Bottom in Shallows	Adult		Seabirds use extensively at rate of 190,000/Day > 250,000,000 Season
Arctic Char *Salvelinus alpinus*									Pelagic	Adult		
Rainbow Smelt *Osmerus eperlanus*												
Pacific Sandlance *Ammodytes hexapterus*	Common	Medium	-	-	-	High			Pelagic	Adult	Calanoid Copepods	Utilized extensively by birds
Greenland Cod [5] *Arctogadus glacialis*								Midwinter		Spawning Adult		Estuarine spawning

BIOLOGICAL RESOURCES OF OFFSHORE PRUDHOE VICINITY (CONT'D.)

AREA: Arctic Prudhoe
SUB-AREA: Cape Thompson
SEASON: Summer Primarily
HABITAT: Estuarine - Soft Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Saffron Cod *Eleginus gracilis*	-	-	-	-	-	-		Midwinter		Spawning Adults		Estuarine spawning
Yellowfin Sole *Limanda aspera*	Rare	-	-	-	-	-				Adults		
Alaska Plaice *Pleuronectes quadrituberculatus*	Rare	-	-	-	-	-				Adults		
Walleye Pollock *Theragra chalcogramma*	Rare	-	-	-	-	-				Adults		

BIOLOGICAL RESOURCES OF OFFSHORE PRUDHOE VICINITY (CONT'D.)

AREA: Arctic
SUB-AREA: -
SEASON: Summer
HABITAT: Open Oceanic and Coastal Pelagic

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Copepods[1,6-10] *Calanus* spp.	Abundant	High?	-	-	-	High	-					45 to 54 percent of zooplankton Biomass
(1) *Pseudocalanus minutus*	Abundant	High	-	-	-	High	-					Endemic Inshore Forms
(2) *Acartia longiremis*	Abundant	High										
(3) *Oithona* spp.												
(4) *Oncaea* spp.												
(1) *Calanus cristatus*	Common		-	-	-	High	-					Expatriate Species from Pacific
(2) *Calanus plumchrus*	Common											
(3) *Eucalanus bungii*	Common											
(4) *Metridia pacifica*	Common											

BIOLOGICAL RESOURCES OF OFFSHORE PRUDHOE BAY VICINITY (CONT'D.)

AREA: Beaufort Sea - Chukchi Sea
SUB-AREA: -
SEASON: Summer
HABITAT: Shallow Offshore - Soft Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Mysids[1,11,12]	Medium	-	-	-	-	High						
Cumacean *Diastylis goodsiri*	-	-	-	-	-	High						
Cragonid Shrimp *Argis lar*	-	-	-	Low	-	High						
Cragonid Shrimp *Sclevocrangon boveae*	-	-	-	Low	-	High						

BIOLOGICAL RESOURCES OF OFFSHORE PRUDHOE BAY VICINITY (CONT'D.)

AREA: Beaufort Sea
SUB AREA: -
SEASON: Summer
HABITAT: Low Salinity Lagoons

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	COMMERCIAL	SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	LIFE HISTORY: DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Mysids[1,11,12]	-	-	-	-	-	High						Washed in with Spring storms
Nemertine *Lepidurus*	-	-	-	-	-							Washed in with spring storms
Mussel *Mytilus edulis*	-	-	-	-	-	Medium						Washed in with Spring storms

BIOLOGICAL RESOURCES OF OFFSHORE PRUDHOE BAY VICINITY (CONT'D.)

AREA: Prudhoe
SUB-AREA: West at Colville River
SEASON: Summer (August)
HABITAT: Estuarine - Soft Bottom

SPECIES	ABUNDANCE BY SUB-AREA	SENSITIVITY TO OIL SPILLS	IMPORTANCE: COMMERCIAL	IMPORTANCE: SUBSISTANCE	IMPORTANCE: RECREATION	IMPORTANCE: ECOLOGICAL	ENDANGERED SPECIES	SPAWNING PERIOD	DEPTH RANGE	LIFE HISTORY: LIFE HIST. STAGE	LIFE HISTORY: FOOD ORGANISMS	REMARKS
Isopod [1] *Mesidotea entomon*	362/ 5 min. ½ m. Net	?	-	-	-	High				Adults		Outside Barrier Islands
Isopod [1] *Mesidotea entomon*	362/ 5 min. ½ m. Net	?	-	-	-	High				Juveniles and Breeding Adults		Migrates to estuarine areas to breed (?)
Mysid [1] *Mysid oculata*	1250/ 5 min. ½ m. Net	High ?	-	-	-	High				Adults		More numerous offshore
Amphipod [1] *Acanthostepheia behringiensis*	Common	?	-	-	-	Medium				Adults		
Amphipod [1] *Gammaracanthus loricatus*	Common	?	-	-	-	Medium				Adults		
Amphipod [1] *Pseudalibrotus litoralis*	Common	?	-	-	-	Medium				Adults		

BIOLOGICAL RESOURCES OF OFFSHORE PRUDHOE VICINITY (CONT'D.)

SOURCES: Tabulated evaluations were made by Charles A. Simenstad, Consultant to MSNW.

1. The Arctic Institute of North America, *THE ALASKAN ARCTIC COAST - A BACKGROUND STUDY OF AVAILABLE KNOWLEDGE*, Contract No. DACW85-74-C-0029, June 1974.

2. Wilimovsky, Norman J. (Editor) and John N. Wolfe (Associate Editor), *ENVIRONMENT OF THE CAPE THOMPSON REGION, ALASKA*, Atomic Energy Commission, Report PNE-481, 1966.

3. McPhail, J. D., and C. C. Lindsay, "Freshwater Fishes of Northwestern Canada and Alaska," *FISH. RES. BD. CANADA, BULL. 173*, 1970.

4. Burns, John J. and James E. Morrow, *ARTIC OIL AND GAS: PROBLEMS AND POSSIBILITIES*, Foundation Francaise D'Etudes Nordiques, Fifth International Congress, Report No., "The Alaskan Arctic Marine Mammals and Fisheries, May 2 through 5, 1973.

5. Walters, V., "Fishes of Western Arctic America and Eastern Arctic Siberia: Taxonomy and Zoogeography," *AM. MUS. NAT. HIST. BULL.*, Vol. 106: 255-294, 1955.

6. English, T. S., "Some Remarks on Arctic Ocean Plankton," *PROCEEDINGS OF THE ARCTIC BASIN SYMPOSIUM*, Arctic Institute of North America, 1963.

7. Hopkins, T. L., "Zooplankton Standing Crop in the Arctic Basin," *LIMNOL. OCEAN*, 14:80-85, 1969.

8. Johnson, M. W., "Arctic Ocean Plankton," *PROCEEDINGS OF THE ARTIC BASIN SYMPOSIUM*, Arctic Institute of North America, 1963.

9. Minoda, T., *SEASONAL DISTRIBUTION OF COPEPODS IN THE ARCTIC OCEAN FROM JUNE TO DECEMBER, 1964*, Records of Oceanographic Works in Japan, 9:161-168, 1967.

10. MacGinitie, G. E., *DISTRIBUTION AND ECOLOGY OF THE MARINE INVERTEBRATES OFF POINT BARROW, ALASKA*, Smithsonian Miscellaneous Collections, Vol. 128, No. 9, 1955.

11. Sparks, A. K., and W. T. Pereyra, "Benthic Invertebrates of the Southeastern Chukchi Sea," *ENVIRONMENT OF THE CAPE THOMPSON REGION ALASKA*, N. J. Williamovsky and J. N. Wolfe, eds., 1966.

12. Naidu, A. S., and G. D. Sharuna, "Geological, Biological, and Chemical Oceanography of the Eastern Central Chukchi Sea," *U. S. COAST GUARD OCEANOGRAPHIC REPORT, 50*, 1972.

OFFSHORE PRUDHOE VICINITY MAMMALS AND BIRDS

ORGANISM GROUPS (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1]	Beaches and Estuaries	Sparse abundance. Possible food impact. Cleanup - possible nuisance conflict.
Polar Bear[1]	Pack Ice Beaches	Mainly associates of pack edge. Must give attention to garbage to avoid attracting animal.
Polar Foxes[1]	Pack Ice and Beaches	Possible food impact, also disturbance of den areas.
Wolves[1]	Beach	Minor food impact. Possible onshore cleanup disturbance of dens.
Moose[1]	Willow - Riparian	Possible disturbance in Winter in feeding areas, Spring calving areas.
Caribou[1]	Shore and Tundra	Possible minor food impact. Cleanup disruption.
Small Mammals[1]	Shore and Tundra	Possible food and cover impact.
Whales[1]	Sea	Number of species, particularly bowhead and beluga whales. (See ADF and G, Page 174.)
Bearded Seal[1]	Pack Ice	Moves with pack ice; non-concentrated population.
Ringed Seal[1, 2]	Pack Ice	Common in coastal area, Winter and Spring migrant.
Ribbon Seal[2]	Pack Ice Edge	Minor occurrence only.
Harbor Seal[2]	Pack Ice and Open Beaches	Heavy utilization of shore areas and edge of pack ice.
Walrus[1]	Pack Ice Open Water	Migrates with ice, Summer occurrences only.
Ducks[1]	Beaches, Sea Estuaries	Mainly sea and diving ducks. Nesting population 16 per square mile. Heavy Arctic migration route through unit. September duck migration of 800,000 ducks - largely eiders and old squaws. Count of 154,000 old squaws migrating past Barrows August 31 to September 7. ADF and G, Page 125.
Geese[1]	Beaches Estuaries	200,000 white front produced in Unit. Brant migrate in September. No firm estimates available.
Swans[1]	Deltas and Estuaries	Unit population estimated at 10,000, mainly whistling swans.
Seabirds[1]	Sea Edge Beaches Estuaries	Two-thirds of bird fauna involving ducks, geese, swans from Canadian Arctic islands migrate through area. Seabird production below relative to more southern sites.
Shorebirds[1]	Beaches Estuaries Deltas	Main impact on food resources of group.

OFFSHORE PRUDHOE VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Upland Game Birds[1]		No significant impact expected.
Raptors[1]		Predator species food supplies possibly affected. Snowy owls, peregrine falcon (endangered), others minimally affected.

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

CLIMATOLOGICAL SUMMARIES

BARROW, ALASKA (Airport Station), 71°18'N., 156°47'W.; Elevation (ground) 22 feet. WB-1961

Month	Air temperature (°F.)					Precipitation (inches)			Humidity (percent)		Wind (knots)					Mean number of days						
	Normal			Extreme												Sunrise to sunset						
	Daily maximum	Daily minimum	Monthly	Record highest	Record lowest	Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	8:00 a.m. Local time	2:00 p.m. Local time	Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				41	41		40	41	17	17	32	12			20	27	27	27	41	17	41	20
Jan.	- 8.5	-21.6	-15.1	33	-53	0.16	0.70	2.1	63	62	9.5	ESE			0	3	2	2	4	1	0	2
Feb.	11.4	-24.3	-17.9	32	-56	0.15	0.36	2.2	62	61	9.8	ENE			5.3	12	6	10	4	•	0	1
Mar.	- 7.8	-21.9	-14.9	30	-52	0.12	0.28	1.6	62	64	9.6	ENE			5.0	14	7	10	3	•	0	1
Apr.	7.4	- 7.7	- 0.2	42	-42	0.10	0.37	1.8	72	73	10.0	NE			5.8	11	7	12	3	1	0	3
May	24.4	13.2	18.8	45	-18	0.13	0.30	1.6	87	85	10.3	ENE			8.4	4	4	23	3	•	0	8
June	38.9	28.9	33.9	70	8	0.28	0.82	0.4	93	90	9.9	E			8.0	5	5	20	4	•	•	13
July	46.0	33.3	39.7	78	22	0.83	0.86	0.7	92	88	10.2	E			8.2	3	7	21	8	•	•	13
Aug.	43.7	33.0	38.4	73	20	0.80	0.83	0.6	94	90	11.0	E			9.0	2	3	26	10	•	•	11
Sep.	34.2	27.0	30.6	62	1	0.55	0.56	2.9	92	89	11.3	E			9.3	2	3	25	9	1	0	5
Oct.	22.0	12.1	17.1	43	-19	0.52	1.00	6.9	85	84	11.9	E			8.8	2	4	25	10	2	0	4
Nov.	6.6	- 5.3	0.7	39	-40	0.27	0.41	3.5	75	74	10.9	E			0	4	3	10	6	•	0	2
Dec.	- 4.2	-16.6	-10.4	34	-55	0.20	0.26	2.7	65	65	10.0	ENE			0	0	0	0	5	•	0	2
Year	15.9	4.2	10.1	78	-56	4.11	1.00	27.0	79	77	10.3	E			-	62	51	184	69	6	•	65

BARTER ISLAND, ALASKA (Airport Station), 70°08'N., 143°38'W.; Elevation (ground) 39 feet. WB-1961

Month	Air temperature (°F.)					Precipitation (inches)			Humidity (percent)		Wind (knots)					Mean number of days						
	Normal			Extreme												Sunrise to sunset						
	Daily maximum	Daily minimum	Monthly	Record highest	Record lowest	Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	8:00 a.m. Local time	2:00 p.m. Local time	Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				12	14		13	13	14	14	13	13			13	13	13	13	12	13	12	13
Jan.	- 8.4	-22.5	-15.5	37	-50	0.39	1.20	5.3	69	68	11.8	E			0	4	2	8	6	1	0	1
Feb.	-10.9	-25.0	-18.0	34	-59	0.35	1.22	3.3	66	67	12.9	W			5.1	10	7	11	5	1	0	1
Mar.	- 6.5	-22.1	-14.3	31	-50	0.26	0.44	2.3	66	67	11.3	W			5.9	8	10	13	6	1	0	2
Apr.	9.3	- 7.3	1.0	43	-37	0.19	0.27	2.2	73	74	10.7	W			6.4	7	8	15	7	•	0	3
May	26.3	14.1	20.2	48	-14	0.22	0.76	3.0	86	85	10.5	E			8.3	3	5	23	7	1	0	8
June	40.4	30.2	35.3	67	18	0.42	1.15	1.5	90	89	9.6	ENE			8.1	2	8	20	7	•	•	11
July	47.0	34.6	40.8	71	25	1.18	1.17	0.4	90	87	8.9	ENE			7.9	2	10	19	10	•	•	15
Aug.	44.4	34.0	39.2	72	24	1.18	1.11	1.5	92	89	10.4	E			8.5	1	8	22	11	1	0	15
Sep.	34.8	27.7	31.3	64	7	0.91	2.23	7.8	91	90	11.0	E			8.6	1	6	23	10	2	0	11
Oct.	22.4	12.3	17.4	43	-16	1.03	1.99	11.1	86	85	13.1	E			8.5	2	6	23	14	4	0	3
Nov.	6.6	- 5.7	0.5	37	-51	0.59	0.43	4.8	76	75	12.6	E			0	4	4	15	9	1	0	3
Dec.	- 4.4	-17.4	-10.9	30	-51	0.46	0.55	2.9	68	70	12.1	W			0	0	0	0	6	1	0	1
Year	16.8	4.4	10.6	72	-59	7.18	2.23	46.1	79	79	11.2	E			-	44	74	192	98	13	•	74

SOURCE: U. S. Department of Commerce and Coastal and Geodetic survey, *PACIFIC AND ARCTIC COASTS - ALASKA, CAPE SPENCER TO BEAUFORT SEA*, Seventh Edition (October 3, 1974), U. S. Coast Pilot Volume 9.

DATA PROCESSING DIVISION
ETAC/USAF
AIR WEATHER SERVICE/MAC

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND
DIRECTION AND SPEED
(FROM HOURLY OBSERVATIONS)

27401 (STATION) — BARTER ISLAND ALASKA MAP (STATION NAME) — 47-70 (YEARS) — ALL (MONTH)

ALL WEATHER (CLASS) — ALL (HOURS (L.S.T.))

(CONDITION)

SPEED (KNTS) DIR.	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥56	%	MEAN WIND SPEED
N	.4	.7	.3	.0	.0	.0						1.4	5.1
NNE	.3	.7	.4	.1	.0							1.4	5.7
NE	.5	1.6	1.9	.8	.2	.1	.0	.0	.0			5.2	8.6
ENE	.4	1.9	4.6	5.0	2.0	.9	.3	.1	.0	.0		15.2	12.3
E	.7	2.5	5.1	6.6	3.2	1.9	.8	.3	.1	.0		21.2	13.7
ESE	.4	1.3	1.9	1.2	.4	.2	.1	.0	.0			5.5	10.3
SE	.3	.7	.7	.2	.0	.0	.0	.0	.0			2.0	7.2
SSE	.2	.3	.3	.0	.0	.0	.0					.8	6.2
S	.3	.8	.8	.1	.0							2.0	6.4
SSW	.3	.8	1.0	.1	.0	.0						2.3	6.5
SW	.5	1.7	2.7	.7	.1	.0	.0	.0	.0	.0	.0	5.8	7.7
WSW	.3	1.3	3.4	1.9	.5	.3	.2	.1	.1	.0	.0	8.1	11.6
W	.4	1.5	3.9	4.7	2.4	1.7	1.0	.5	.1	.1	.0	16.4	15.5
WNW	.3	.9	1.6	1.3	.6	.3	.1	.0	.0	.0	.0	5.2	11.7
NW	.4	1.0	.7	.3	.1	.0	.0	.0		.0	.0	2.4	7.1
NNW	.2	.5	.2	.0	.0	.0						1.0	5.6
VARBL													
CALM												4.1	
	6.0	16.3	29.4	23.0	9.6	5.5	2.5	1.2	.3	.2	.1	100.0	11.2

TOTAL NUMBER OF OBSERVATIONS 162511

SOURCE: National Climatic Center, *SSWO (PART C)*.

USAFETAC FORM JUL 64 0-8-5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

NORTH SLOPE - SURFACE WINDS

Station	Winter		Summer		Fastest Mile		2nd Fastest Mile	
	Prevailing Direction	Mean Speed (mph)	Prevailing Direction	Mean Speed (mph)	Direction	Speed (mph)	Direction	Speed (mph)
Barter Island	W E	14	E NE	12	SW	81	W	78
Umiat	W	8	E NE	10	W	>47		
Barrow	E NE	11	E	12	W	58	W	55
Wainwright	E		E SW					
Point Lay								
Cape Lisburne	E SE	13	E NE SW	12		>65		55
Point Hope	NE S	16	NE S	11	E	68	NE E	59

SOURCE: Swift, W. H., R. E. Brown, I. V. Kinnel, M. M. Orgel, P. L. Petersen, W. W. Waddell, *GEOGRAPHICAL ANALYSIS OF OIL SPILL POTENTIAL ASSOCIATED WITH ALASKAN OIL PRODUCTION AND TRANSPORTATION SYSTEMS*, Pacific Northwest Laboratory, Division of Memorial Institute to the United States Coast Guard, February 1974, Final Report No. CG-D-79-74.

ONSHORE PRUDHOE: INFORMATIONAL RESOURCES

See Offshore Prudhoe Section for information on salmonids, marine fish, invertebrates and marine vegetation involved at this location when the oil spills into the Sagavanirktok and reaches the sea.

- Onshore Prudhoe Vicinity Mammals and Birds

ONSHORE PRUDHOE VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1]	Streams Grass Flats	Possible food resource disruption - fish and grass. Cleanup conflict a possible problem.
Polar Bear[1]	Beaches and Sea	Possible spread to sea.
Polar Foxes[1]	Pack Ice and Beaches	Possible disruption of food and denning activity in Spring.
Wolves[1]	General	Possible food base disruption.
Moose[1]	Streams, Rivers, Riparian Vegetation	Possible food disruption; disturbance of calving areas.
Caribou[1]	Low Tundra	Migration disturbance; food base loss.
Small Mammals[1]	Tundra	Possible food and cover loss. Important as a food source for predators.
Ducks[1]	Potholes	Sixteen breeders per square mile. Possible damaged habitat - slow recovery. Migration area.
Geese[1]	Potholes	Possible breeding and brooding loss. Mainly white fronts (200,000 produced in Unit), brant; migration area. Recovering snow goose stocks.
Swans[1]	Potholes	Heavy use of deltas by whistling swans.
Shorebirds[1]	Tundra Pothole Edges	Possible breeding losses and impact on foods.
Seabirds[1]		
Upland Game Birds[1]		
Raptors[1]		

SOURCES: 1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

UMIAT: INFORMATIONAL RESOURCES

See Offshore Prudhoe Section for information on salmonids, marine fish, invertebrates, and marine vegetation involved at this location when the oil spills into the Colville River and reaches the sea.

- Umiat Vicinity Mammals and Birds
- Surface Winds - Umiat

UMIAT VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1, 2]	River Valleys and Tundra	Densities established at one per 100 square miles; kills since 1961 - 6 to 23, most by sport hunters.
Polar Bear[1, 2]	Beaches Ice Edge	Only occasionally present - may use beaches and nearshore tundras. Rare denning records ashore - population stable.
Wolves[1, 2]	Tundra and Rivers	Population rising following intense control in the 1960's. Takes have ranged from 45 to 162 since 1961. Vulnerable in open habitats. Protected from aerial hunting. Wide fluctuations in numbers due to food variances.
Wolverine[1, 2]	River Valleys	Distribution as during aboriginal times. Actively hunted and trapped. Moderate population.
Caribou[1, 2]	Tundra River Valleys	Formerly abundant in Colville River area - declined and currently in recovery phase. Important calving area at head of Colville. Return to calving area in March. Some wintering in coast areas. Pipeline crosses eastern portion of range. Concern for free herd movement. Local restriction on herd believed already occurring. Estimate 250,000 to 300,000 in Unit. Coast ranges important Summer areas.
Moose[1, 2]	Rivers Willow Flats Riparian Vegetation	Occur throughout area. Recent spread to area and population increasing. Colville River prime area of whole unit. Harvest 50 to 100 annually.
Muskox[1, 2]	Tundra	Reintroduced herd established and believed spreading. Eventual likelihood in site area in the future.
Walrus[1]	Pack Ice Open Seas	Migrants reach Barrows by early August - reverse migration in October. Most to west of site - but high populations east.
Ringed Seal[1]	Pack Ice Coastal Seas	Migrate with ice edge until it leaves coast. Mainly associated with narrow fringes of land-fast ice and along pack ice edge. Reverse migration in October
Harbor Seal[1]	Pack Edge Coastal Seas	Disperse along coast as seas open.
Northern Fur Seal[2]	Pelagic	Incidental occurrences only.
Bearded Seal[1]	Pack Ice	Mainly associated with pack ice; Summer distributed along pack edge.

UMIAT VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Whales[1]	Open Seas	Sixteen species in offshore waters.
Ducks	Nearshore Seas Rivers Delta Potholes	Average breeding density of 16 per square mile. Two-thirds of Arctic waterfowl migrate through area. An estimated 800,000 waterfowl pass Barrow in September. Area important breeding area.
Geese[1]	Nearshore Seas Rivers Delta Potholes	Important breeding, nesting and migration area. Snows, brant, white fronts (175,000 to 200,000 white fronts migrate through area).
Swans[1]	Nearshore Seas Rivers Delta Potholes	Migration of 10,000 whistlers through area. Also breeders - concentrations in Colville.
Seabirds[1, 2]	Deltas Nearshore Seas	Important migration area. Some breeders.
Shorebirds[1, 2]	Deltas Beaches	Important migration area. Some breeders.
Upland Game Birds[2]	River Valleys	Ptarmigan.
Non-Game Birds[2]	Deltas	
Aquatic Furbearers[2]	Rivers	Fair population likely in lower delta. Vulnerable to spills.
Small Terrestrial Mammals[2]	River Valleys Tundra	Low population expected.

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

DATA PROCESSING DIVISION
ETAC/USAF
AIR WEATHER SERVICE/MAC

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND
DIRECTION AND SPEED
(FROM HOURLY OBSERVATIONS)

26537 — UMIAT ALASKA — 46-55 — ALL
STATION — STATION NAME — YEARS — MONTH

ALL WEATHER — ALL
CLASS — HOURS (L.S.T.)

CONDITION

SPEED (KNTS) DIR.	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥56	%	MEAN WIND SPEED
N	.9	.0	.6	.2	.0	.0						2.3	5.6
NNE	.5	.7	1.1	.6	.1	.0	.0					2.9	6.1
NE	2.[illegible]	2.1	3.3	1.5	.3	.1	.0	.0				9.6	7.9
ENE	1.[illegible]	1.2	1.9	2.0	.4	.2	.0	.0				6.7	9.6
E	3.7	3.6	3.9	2.3	.3	.1	.0	.0				14.6	7.0
ESE	.6	.6	.4	.1	.0	.0						1.8	5.7
SE	.7	.3	.1	.1								1.1	3.0
SSE	.1	.1	.1	.0	.0	.0	.0					.3	6.5
S	.4	.2	.1	.1	.1	.0	.0	.0				.9	6.7
SSW	.2	.2	.2	.1	.0	.0	.0					.8	6.3
SW	1.0	1.3	1.2	.5	.1	.0	.0					4.9	6.2
WSW	1.7	2.3	2.8	1.6	.5	.3	.1	.0	.0	.0	.0	9.5	6.7
W	6.7	6.1	4.0	1.6	.5	.3	.1	.0	.0	.0		20.4	6.4
WNW	.7	.7	.7	.4	.1	.1	.0	.0	.0	.0		2.5	6.1
NW	1.4	.8	.7	.4	.1	.0	.0		.0			3.3	6.2
NNW	.4	.3	.4	.1	.0	.0						1.2	6.5
VARBL													
CALM												17.1	
	22.9	21.1	22.5	12.5	2.5	1.1	.2	.1	.0	.0	.0	100.0	6.0

TOTAL NUMBER OF OBSERVATIONS 69246

SOURCE: National Climatic Center, *SSMO (PART C)*.

USAFETAC FORM JUL 64 0-8-5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

YUKON RIVER CROSSING: INFORMATIONAL RESOURCES

- Yukon River Crossing - Denali Fault Crossing Salmonid Resources
- Yukon River Crossing Vicinity Mammals and Birds

YUKON RIVER CROSSING - DENALI FAULT CROSSING SALMONID RESOURCES

Chum salmon are the most abundant, followed by king, coho, and insignificant numbers of pink and sockeye. Most of the commercial and subsistence fishery occurs in the river. The runs occur June through August with the kings showing early (June-July) and the chums and coho late (July-August). There are some summer run chums (June-July), most of the fishermen are local residents so the fishery is important to the local economy. The estimated value of the king salmon run to commercial and subsistence fishermen is $1 million to $1.5 million annually. The commercial value for coho is approximately $20,000. The commercial value of the chum catches has been approximately $250,000 but the potential value with increased harvest is approximately $1 million. Chum subsistence catches have an estimated value of approximately $300,000.

There is extensive sport fishing in the Yukon drainage for grayling and arctic char. The Chena river alone accounts for 25,000 man days annually.

Mean commercial catches for the Alaskan Yukon are listed below (1965-1973)

	CATCH IN THOUSANDS	RANGE
Chum	205.1	(23.2 - 517.9)
Coho	16.0	(00.7 - 036.6)
King	99.5	(79.3 - 118.0)

Mean commercial catches for Yukon Territory (1965-1973 in thousands)

Chum	2.3	(00.4 - 003.3)
King	2.2	(01.6 - 003.2)

Mean subsistence catches for Alaskan Yukon (1965-1973 in thousands)

King	16.1	(11.6 - 022.5)
Other Salmon (Mostly Chum)	227.0	(133.1 - 448.9)

Mean subsistence catch for Yukon Territory (1965-1973 in thousands)

King	2.4	(01.0 - 003.0)
Other (Mostly Chum)	10.4	(01.2 - 014.0)

YUKON RIVER CROSSING - DENALI FAULT CROSSING SALMONID RESOURCES (CONT'D.)

SOURCES: Compilation by Larry G. Gilbertson, Consultant to MSNW

1. International North Pacific Fisheries Commission. Statistical Yearbook (for the years stated).

2. State of Alaska, Department of Fish and Game, Arctic-Yukon-Kuskokwin (A-Y-K) Region Subsistence Fishery Report, Manuscript prepared by A-Y-K Staff, 1972.

3. Anonymous, *FISHERY STATUS REPORT, NORTHERN REGION, YUKON AREA*, ADF and G, Region III, Fairbanks.

YUKON RIVER CROSSING VICINITY MAMMALS AND BIRDS

ORGANISM GROUP	HABITATS OF CONCERN	GENERAL COMMENTS
Brown Bear[1, 2]	River and Stream Edges Deltas	Population low to moderate. Main concern is damage to salmon as food for bears.
Black Bear[1, 2]	River Valleys Ledge Meadows	Distribution roughly corresponds with timber distribution.
Wolves and Wolverines[1, 2]	River Valleys	Wolf harvest Unit 20 - 90 to 336, Unit 25 - 25 to 145 per year. Populations highly variable with time. Important species for fur, sport, ecologically. Wolverine same importance.
Moose[1]	River Valleys Deltas Riparian Willow Stands and Meadows	Yukon Flats - 6,000 in 1962. Unit 25 harvest 700 to 800 annually; 496 harvested in Unit 20 along Yukon in 1971. Unit 19 harvest 500 to 700 annually. High population generally at other sites. Important subsistence and sport animal. Heavy wintering along Yukon River.
Caribou[1]	Low Tundra River Migration Sites	Important porcupine herd to east. Forty mile herd borders south edge of Yukon and variously migrates back and forth across the Yukon River. Herd estimated at 15,000; kill in 1971 estimated at 2,500. McKinley herd to the west estimated at 10,000.
Aquatic Furbearers[2]	Rivers Shore Edges	Beaver, otter, mink in vicinity. All subject to spill damage.
Ducks[1]	River Deltas Lowland Meadows	Yukon Flats 100 ducks per square mile. $\bar{x}$ 67 ducks per square mile in Units 19 and 20. Annual production 600,000 to 1-1/4 million. Area one of most productive in State. Possible downstream spill impact.
Geese[2]	River Deltas Lowland Meadows	Fair populations of Canada and white front geese.
Shorebirds[1, 2]	River Edges and Bars Lowlands	Little brown crane nests throughout the Unit.
Upland Game Birds[2]	Riparian Vegetation	Ptarmigan population subject to damage in riparian zone.
Non-Game Birds[2]	Riparian Vegetation Lowlands	
Other Small Mammals[2]	Riparian Vegetation Lowland Areas	Primarily important as food organisms, ecological species.
Raptors[2]		Possible food organism impact.

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

DENALI FAULT: INFORMATIONAL RESOURCES

See Yukon River Crossing section for information for this location on salmonids.

- Denali Fault Vicinity Mammals and Birds

DENALI FAULT VICINITY MAMMALS AND BIRDS

ORGANISM GROUP (1)	HABITATS OF CONCERN (2)	GENERAL COMMENTS (3)
Brown Bear[1]	Fish Spawning Areas Grassy Riparian Areas	Low population generally. Population would likely be greater but area in high human use.
Black Bear[2]	Riparian Grass Areas Streams	Moderate population. Important in sport kill.
Moose[1, 2]	Riparian River Zone	Important moose game unit. This part of unit of lesser importance, however. In 1971 23 were reported harvested. Two intense Fall use areas just below Black Rapids. Important riparian vegetation. Heavy use in Winter.
Wolves and Wolverines[1]	River Valley	Seventy-five wolverines trapped annually in unit. Wolf important fur and sport animal in unit and ecologically important.
Caribou[1]	River Valley	Wintering area just upstream from spill site. Components of small delta herd present throughout area - 50,000 estimated herd size.
Bison[1]	River Valley Riparian Zone	Important bison range just south of Black Rapids including a principal calving area. Herd migrates seasonally between Delta River and a point just south of site.
Aquatic Furbearers[2]	Rivers and Lowland Water Areas	Low populations of mink, muskrat, beaver, otter. Damage with contact and food base loss.
Other Mammals[2]	Riparian Vegetation and Lowland Areas	Some high density rabbit areas. Main concern ecological influence.
Upland Game Birds[2]	Riparian Vegetation	Important game bird hunting zone - ptarmigan.
Ducks[1]	River Systems Flooded Lowlands	Unit duck breeding density 67 per square mile. Bird list heavy original and some current subsistence hunting - little in area, however. Important nesting and moulting area below Black Rapids. Important migration corridor.
Geese[1]	River Systems Flooded Lowlands	Important migration zone. Breeding and moulting below site.
Shorebirds[1, 2]	River Edges Bars, Deltas	Important migration route. Breeding population below Black Rapids.
Non-Game Birds[2]	Riparian Vegetation	Mainly influenced during migration.

SOURCES:

1. Alaska Department of Fish and Game, *ALASKA'S WILDLIFE AND HABITAT*, January 1973.

2. A. W. Erickson, personal communication.

APPENDIX E

MSNW OIL SPILL DISPERSION MODEL INPUT INSTRUCTIONS AND PROGRAM LISTINGS

This model was designed to run batch mode on a CDC 6400 computer under the SCOPE 3.4 operating system. The program was compiled and stored on a disk permanent file alona with the digitized geograpnic data. The CalComp plotter is off-line so a tape file (TAPE99) is created which saves the results of each model iteration for subsequent plotting.

Table E-1 illustrates the control card set-up for a typical run. Table E-2 defines the input data formats.

A typical run requires approximately 150 seconds of central processor (CPU) time on the CDC 6400, plus about 4 to 5 minutes of plotter time. The plotting time is a function of map size and shoreline complexity. The total cost of a typical run is between $10 and $20, based on the University of Washington's current commercial rates.

Figure E-1 is an example of the physical parameter listing. Figure E-2 is an example of the printed output. The first column is simply a count of the iterations (time steps). The second column shows the elapsed computer time in seconds. The third column is the simulated model time in hours. These numbers are not even due to the fact that the model adjusts the time steps to coincide with the times of changing from one spread regime to another.

The fourth column is the current slick area in square meters. NPOINTS is the number of points currently being used to define the slick edge. The number of points can be seen to change over time as the geometry of the slick evolves.

SPREAD is the magnitude of the spread vector in centimeters and PLOT indicates which iterations have been plotted this particular run.

TABLE E-1. DECK SET-UP FOR TYPICAL RUN

MSNWSLICK, T150.	(Job Card)
ACCOUNT, JOBNUMBR, PASSWRD.	(Account Card)
ATTACH, GRAFIX. LIBRARY, GRAFIX.	(Load Plot Routines)
DISPOSE, TAPE99, *CC.	(Establish Plot Tape)
REQUEST, TAPE 2, *PF.	(Auxiliary Plot Tape)
ATTACH, TAPE1, PORTGRAHAM, ID=STORIE	(Geographic Data)
ATTACH, SPILL, SLICK, ID=STORIE.	(Load Program)
SPILL.	(Execute Program)
EXIT, P.	(Error Recovery Step)
CATALOG, TAPE2, PLOT, ID=STORIE.	(Save Auxiliary Plots)
7/8/9	(End of Record)
DATA DECK	
6/7/8/9	(End of Job)

For further information see:

Control Data Corporation, *SCOPE REFERENCE MANUAL,* CDC 6000 Computer Systems, Version 3.4.1.

TABLE E-2. OIL SPILL SIMULATION MODEL INPUT DATA.

1. Heading Cards (8A10/8A10)

Two heading cards with up to 80 characters each. Either or both cards may be blank.

2. Program Control Card

Cols.	Type	Description
1-10	Real	Time increment between successive iterations in hours.
11-20	Real	Maximum time of simulation, hours.
21-30	Real	Scale of Digitized geographic data.
32	Integer	1 = List Tidal Polygon Data 0 = Do Not List
34	Integer	1 = Plot Tidal Polygons 0 = Do Not Plot
36	Integer	1 = List Wind Data 0 = Do Not List
38	Integer	1 = Read Tidal Current Curve 0 = Use Sinusoid
41-43	Integer	Initial number of points defining slick edge.
51-60	Real	Size factor for output plots.

3. Pilot Control Card (40I2)

Cols.	
1- 2	First iteration to be plotted.
3- 4	Second iteration to be plotted.
5- 6	Third iteration to be plotted.
	Etc.

Iterations will be plotted every 6 hours after the last value given or if no values are given.

TABLE E-2. (CONT'D.)

4. Physical Properties Card

Cols.		
1-10	XCORD	(x-coordinate of spill location in inches)
11-20	YCORD	(y-coordinate of spill location)
21-29	VOLUME	(volume of oil spilled)
30	C1 = B C1 = T C1 = G	(units are barrels) (units are tons) (units are gallons)
31-40	RHOOIL	(density of oil)
41-50	NU	(kinematic viscosity of water)
51-60	RHOWATR	(density of water)
61-70	SIGMA	(interfacial tension)

5. Tide Curve Cards (Optional)
(I10, F10.0)

Cols.	
1-10	Hour
11-20	Current magnitude

6. Tidal Current Default Card
(5F6.0, 1X, A1, 1X, A10, A2, 5X, F10.0, A1)

Cols.	
1- 6	Direction of flood (degrees from North).
7-12	Magnitude of flood.
13-18	Direction of ebb (degrees from North).
19-24	Magnitude of ebb.
25-30	Number of additional tidal polygons.
32	K = magnitude is knots (default) M = meters per second F = MPH

TABLE E-2. (CONT'D.)

Cols.	
34-45	Name of spill site.
51-60	OFFSET from maximum ebb, hours.
61	Offshore current indicator.

7. Tidal Current Polygon Card(s) (12F6.0)

Cols.		
1- 6	Direction of flood (degrees).	
7-12	Flood magnitude factor or current ratio.	
13-18	Direction of ebb (degrees).	
19-24	Ebb magnitude factor.	
25-30	X1	Vertices of polygon (inches)
31-36	Y1	
37-42	X2	
43-48	Y2	
49-54	X3	
55-60	Y3	
61-66	X4	
67-72	Y4	

8. Wind Data Card (F10.0, F9.0, A1)

Cols.	
1-10	Wind direction (degrees).
11-19	Wind speed.
20	K = knots (default) M = meters per second F = MPH

TABLE E-2. (CONT'D.)

AUXILIARY PLOT PROGRAM

1. <u>Heading Cards</u> (8A10/8A10)

2. Site name and reduction factor.

Cols.	
1-12	Site name (must match tape).
21-30	Plot reduction factor (default = 1.0)

3. Plot Control Card (iterations to be plotted) (40I2)

```
MATHEMATICAL SCIENCES NORTHWEST
OIL SPILL SIMULATION MODEL

DRIFT RIVER      50,000 BBLS.  NO. 2 DIESEL OIL
WIND NNE AT 6.0 KNOTS       WINTER     25/0.65

PHYSICAL PROPERTIES

  SPILL LOCATION -  X-COORDINATE =  8.05, Y-COORDINATE = 11.35  (INCHES)

  TIME INCREMENT (DELTA-T) =  1.000, HOURS,     3600 SECONDS

  SIMULATION TIME LIMIT =  73.00 HOURS

  SPILL VOLUME -
      50000.00 BARRELS
    2100000.00 GALLONS
       7431.85 SHORT TONS
    7.9485E+09 CUBIC CENTIMETERS

  OIL DENSITY =  .850 GRAMS PER CUBIC CENTIMETER
  WATER DENSITY = 1.000 GRAMS PER CUBIC CENTIMETER
  DENSITY RATIO (DELTA) =  .150
  KINEMATIC VISCOSITY OF WATER (NU) =  .010 SQUARE CENTIMETERS PER SEC
  INTERFACIAL TENSION (SIGMA) = 25.000 DYNES PER CENTIMETER
```

FIGURE E-1. PHYSICAL PROPERTIES INPUT

MATHEMATICAL SCIENCES NORTHWEST
OIL SPILL SIMULATION MODEL

DRIFT RIVER 50,000 BBLS. NO. 2 DIESEL OIL
WIND NNE AT 6.0 KNOTS WINTER 2570.85

SPREAD LIMIT = 84180962 SQ METERS

ITERATION	CP SECONDS	MODEL TIME	SLICK AREA	NPOINTS	SPREAD	PLOT
1	9.306	1.276	2017347	36	80338	X
2	10.243	2.276	2694383	36	12537	X
3	11.155	3.276	3232600	35	8851	X
4	12.100	4.276	3693198	36	7064	X
5	13.053	5.276	4102465	36	5864	X
6	13.988	6.276	4474341	36	5081	X
7	14.932	7.276	4817649	36	4505	X
8	15.888	8.276	5138069	36	4062	X
9	16.825	9.276	5439047	36	3709	X
10	17.747	10.276	5725362	36	3420	
11	18.747	11.276	5997481	36	3179	
12	19.747	12.276	6475424	36	2974	X
13	20.750	13.276	7654040	35	2798	
14	21.775	14.276	9841302	36	2644	X
15	22.776	15.276	12578334	36	2508	
16	23.853	16.276	15318401	38	2388	
17	25.139	17.276	15698632	40	2280	X
18	26.335	18.276	16404476	40	2183	
19	27.586	19.276	17776735	40	2095	
20	28.877	20.276	19555538	39	2015	X
21	30.125	21.276	21727363	38	1942	
22	31.527	22.276	23695033	41	1875	
23	33.047	23.276	25312732	45	1813	X
24	34.606	24.276	25825585	46	1755	

FIGURE E-2. PRINTED OUTPUT OF OIL SPILL MODEL

(10) PROGRAM LISTINGS

The following is a listing of the oil spread computer model complete with subroutines.

```
      PROGRAM SLICK (INPUT,OUTPUT,TAPE99,TAPE1,TAPE2,TAPE5=INPUT,
     & TAPE6=OUTPUT)
      INTEGER CON(3),HEAD1(8),HEAD2(8),REGIME,C1,C2,C3,SITE(2),GUESS
      INTEGER NPLOT(40),OFFSHOR
      LOGICAL IN
      REAL XX(4),YY(4),POLYGON(21,12),SLICK(101,3),NU,K2I,K2V,K2T
      REAL WIND(2),XSLICK(101),YSLICK(101),XDUMY(101),YDUMY(101)
      REAL XVIRT(101),YVIRT(101)
      EQUIVALENCE (XSLICK,SLICK(1)),(YSLICK,SLICK(102))
C---------CHECK INITIAL CP TIME
      CALL SECOND(T)
      WRITE (6,5) T
    5 FORMAT (///1X*ELAPSED CP TIME =*F9.3)
C---------INITIALIZE CONSTANTS
      EPS=0.0001
      MPLOT=1
      PI=3.14159
      K2I=1.14
      K2V=1.45
      K2T=2.05
      G=980.7
C---------INITIALIZE PLOT
      CALL PLOTS
C---------READ HEADINGS
      READ (5,10) HEAD1,HEAD2
   10 FORMAT (8A10/8A10)
C---------READ PROGRAM CONTROL CARD
      READ (5,20) HOURS,QUIT,SCALE,CON,NPOINTS,SHRINK
   20 FORMAT (3F10.0,3I2,4X,I3,7X,F10.0)
C---------DEFAULT VALUE FOR SHRINK FACTOR IS 1.0
      IF (SHRINK .LE. 0.) SHRINK=1.0
C---------ESTABLISH SIZE OF PLOT
      CALL FACTOR (SHRINK)
C---------CONVERT TIME TO SECONDS
      DELTAT=HOURS*3600.
C---------READ PLOT CONTROL CARD
      READ (5,25) NPLOT
   25 FORMAT (40I2)
C---------FIND MAXIMUM ITERATION SPECIFIED
```

```
      MAXPLOT=0
      DO 28 I=1,40
      IF (NPLOT(I) .GT. MAXPLOT) MAXPLOT=NPLOT(I)
   28 CONTINUE
C---------READ PHYSICAL PROPERTIES CARD
      READ (5,30) XCORD,YCORD,VOLUME,C1,RHOOIL,NU,RHOWATR,SIGMA
   30 FORMAT (2F10.0,F9.0,A1,4F10.0)
C---------CONVERT UNITS OF SPILL VOLUME TO CUBIC CENTIMETERS
C---------VOLUME IN TONS
      IF (C1 .NE. 1HT) GO TO 40
      TVOL=VOLUME
      CCVOL=VOLUME*10.**6/2.2/RHOOIL
      BVOL=TVOL*20./1.5897/RHOOIL/2.2
C---------CHECK ON LB-KG CONVERSION IN ABOVE
      GVOL=BVOL*42.
      GO TO 60
C---------VOLUME IN GALLONS
   40 IF (C1 .NE. 1HG) GO TO 50
      GVOL=VOLUME
      BVOL=GVOL/42.
      TVOL=BVOL*1.5897*RHOOIL*2.2/20.
      CCVOL=BVOL*1.5897*10.**5
      GO TO 60
C---------VOLUME IN BARRELS
   50 BVOL=VOLUME
      CCVOL=VOLUME*1.5897*10.**5
      GVOL=BVOL*42.
      TVOL=BVOL*1.5897*RHOOIL*2.2/20.
C---------PRINT HEADINGS
   60 WRITE (6,70) HEAD1,HEAD2
   70 FORMAT (1H1,52X*MATHEMATICAL SCIENCES NORTHWEST*/53X*OIL SPILL SIM
     $ULATION MODEL*//1X,8A10/1X,8A10/)
C---------PRINT PHYSICAL PROPERTIES
      WRITE (6,80)
   80 FORMAT (1X*PHYSICAL PROPERTIES*/)
      WRITE (6,90) XCORD,YCORD
   90 FORMAT (3X*SPILL LOCATION -  X-COORDINATE =*F6.2*, Y-COORDINATE =*
     $ F6.2*  (INCHES)*/)
      WRITE (6,100) HOURS,DELTAT
```

```
  100 FORMAT (3X*TIME INCREMENT (DELTA-T) =*F7.3*, HOURS,*F8.0
     $ * SECONDS*/)
      WRITE (6,105) QUIT
  105 FORMAT (3X*SIMULATION TIME LIMIT =*F7.2* HOURS*/)
      QUIT=QUIT*3600.
      WRITE (6,110) BVOL,GVOL,TVOL,CCVOL
  110 FORMAT (3X*SPILL VOLUME -*/5X,F10.2* BARRELS*/5X,F10.2* GALLONS*/
     $ 5X,F10.2* SHORT TONS*/5X,E10.4* CUBIC CENTIMETERS*/)
C--------COMPUTE DENSITY RATIO
      DELTA=1.-RHOOIL/RHOWATR
      WRITE (6,120) RHOOIL,RHOWATR,DELTA,NU,SIGMA
  120 FORMAT (3X*OIL DENSITY =*F6.3* GRAMS PER CUBIC CENTIMETER*/
     $ 3X*WATER DENSITY =*F6.3* GRAMS PER CUBIC CENTIMETER*/3X
     $ *DENSITY RATIO (DELTA) =*F6.3/3X
     $ *KINEMATIC VISCOSITY OF WATER (NU) =*F6.3* SQUARE CENTIMETERS PER
     $ SEC*/3X*INTERFACIAL TENSION (SIGMA) =*F7.3* DYNES PER CENTIMETER*
     $ /)
C--------READ DEFAULT TIDAL CONDITIONS, NUMBER OF TIDAL POLYGONS,
C           SITE NAME, OFFSET, AND OFFSHORE PARAMETER
      READ (5,130) (POLYGON(21,J),J=1,5),UNIT,SITE,OFFSET,OFFSHOR
  130 FORMAT (5F6.0,1X,A1,1X,A10,A2,5X,F10.0,A1)
C--------WRITE SITE NAME AND COORDINATES OF SPILL LOCATION ON
C           THE AUXILLIARY PLOT FILE
      WRITE (2,135) SITE,XCORD,YCORD
  135 FORMAT (A10,A2,3X,2F10.3)
C--------CONVERT OFFSET TIME TO SECONDS
      OFFSET=OFFSET*3600.
C--------TEST FOR ZERO TIDAL POLYGONS
      NPOLY=POLYGON(21,5)+0.5
      IF (NPOLY .EQ. 0) GO TO 175
C--------TEST FOR NUMBER OF POLYGONS (MAX=20)
      IF (NPOLY .LE. 20) GO TO 150
      WRITE (6,140)
  140 FORMAT (//1X*YOU HAVE SPECIFIED MORE THAN 20 TIDAL POLYGONS*//
     $ 1X*CRASH*//)
      STOP
C--------READ TIDAL POLYGONS
  150 DO 160 I=1,NPOLY
  160 READ (5,170) (POLYGON(I,J),J=1,12)
```

```
  170 FORMAT (12F6.0)
C--------TEST FOR LISTING OF TIDAL POLYGONS
  175 IF (CON(1) .EQ. 0) GO TO 240
      WRITE (6,70) HEAD1,HEAD2
C--------LIST TIDAL POLYGONS
      WRITE (6,180)
  180 FORMAT (1X*TIDAL POLYGON DATA*/)
      IF (OFFSHOR .NE. 1H ) WRITE (6,185)
  185 FORMAT (1X,3H***THIS DATA REPRESENTS AN OFF-SHORE CURRENT*/
     $ 4X*WHERE THE CONCEPTS OF EBB AND FLOOD ARE NOT APPLICABLE*/)
      WRITE (6,190)
  190 FORMAT (13X*---------FLOOD----------      -----------EBB-----------
     $     -----------COORDINATES IN MAP INCHES------------*)
      WRITE (6,200)
  200 FORMAT (1X*POLYGON     DEGREES   KNOTS    FACTOR     DEGREES   KNOT
     $S   FACTOR           X1     Y1     X2     Y2     X3     Y3     X4     Y4*/)
C--------PRINT DEFAULT TIDAL CONDITIONS
      EBB=1.0
      FLOOD=1.0
      WRITE (6,210) POLYGON(21,1),POLYGON(21,2),FLOOD,POLYGON(21,3),
     $ POLYGON(21,4),EBB
  210 FORMAT (1X*DEFAULT*5X,F7.0,F8.2,F9.3,5X,F7.0,F8.2,F9.3/)
C--------PRINT POLYGON DATA
      IF (NPOLY .EQ. 0) GO TO 240
      DO 220 I=1,NPOLY
      FLOOD=POLYGON(I,2)*POLYGON(21,2)
      EBB=POLYGON(I,4)*POLYGON(21,4)
  220 WRITE (6,230) I,POLYGON(I,1),FLOOD,POLYGON(I,2),POLYGON(I,3),
     $ EBB,(POLYGON(I,J),J=4,12)
  230 FORMAT (1X,I7,5X,F7.0,F8.2,F9.3,5X,F7.0,F8.2,F9.3,5X,8F6.2)
C--------CONVERT DEFAULT TIDAL CURRENTS FROM KNOTS TO CM/SEC
  240 POLYGON(21,2)=POLYGON(21,2)*1852./3600.*100.
      POLYGON(21,4)=POLYGON(21,4)*1852./3600.*100.
C--------TEST FOR PLOT OF TIDAL POLYGONS
      IF (CON(2) .EQ. 0) GO TO 280
      IF (OFFSHOR .NE. 1H ) GO TO 280
C--------SEE IF THERE ARE ANY TIDAL POLYGONS
      IF (NPOLY .GT. 0) GO TO 250
      WRITE (6,250)
```

```
  250 FORMAT (1H1*THERE ARE NO TIDAL POLYGONS TO PLOT*//)
      GO TO 280
C--------CALL GEOGRAPHIC PLOTTING SUBROUTINE
  260 CALL GEOPLOT (SITE,HEAD1,HEAD2,XCORD,YCORD)
C--------PLOT POLYGON HEADING
      CALL SYMBOL (0.,-.5,.35,14HTIDAL POLYGONS,0.,14)
C--------PLOT POLYGONS
      DO 270 I=1,NPOLY
      CALL PLOT (POLYGON(I,5),POLYGON(I,6),3)
      CALL DASHPT (POLYGON(I,7),POLYGON(I,8),0.07)
      CALL DASHPT (POLYGON(I,9),POLYGON(I,10),0.07)
      CALL DASHPT (POLYGON(I,11),POLYGON(I,12),0.07)
  270 CALL DASHPT (POLYGON(I,5),POLYGON(I,6),0.07)
C--------MOVE TO A NEW PLOT ORIGIN
      CALL PLOT (25.,0.,-3)
C--------READ WIND DATA CARD
  280 READ (5,290) WIND,C1
  290 FORMAT (F10.0,F9.0,A1)
C--------CONVERT UNITS (CM/SEC USED IN COMPUTATION)
      IF (C1 .NE. 1HK) WRITE (6,300)
  300 FORMAT (1H1*I AM ASSUMING THAT YOU GAVE ME WIND SPEED IN KNOTS*)
      WKNOTS=WIND(2)
      WIND(2)=WIND(2)*1852./3600.*100.
      WMILES=WIND(2)/100./.3048/5280.*3600.
C--------CONVERT WIND DIRECTION
      WD=WIND(1)*1.0
C--------SEE POLLUTION MODEL AT STATEMENT NO 620
  400 CONTINUE
  420 WIND(1)=(WD-180.0)/57.29578
C--------TEST FOR LISTING OF WIND DATA
      IF (CON(3) .EQ. 0) GO TO 450
      WRITE (6,70) HEAD1,HEAD2
      WRITE (6,430)
  430 FORMAT (1X*WIND DATA*/)
      WRITE (6,440) WD,WKNOTS,WMILES,WIND(2)
  440 FORMAT (/3X*DIRECTION =*F6.0* DEG FROM NORTH*/3X*AT*F10.2* KNOTS*
     $ /5X,F10.2* MPH*/1X,F14.0* CM/SEC*)
C--------INITIALIZE SLICK ARRAY
  450 DO 460 I=1,101
```

```
      SLICK(I,1)=XCORD
      SLICK(I,2)=YCORD
  460 SLICK(I,3)=0.
C---------INITIALIZE TIME
      TLAST=0.
C---------COMPUTE TIMES OF TRANSITION BETWEEN SPREAD MECHANISMS
C---------INERTIAL TO VISCOUS
      TAU1=((K2V/K2I)**4)*(CCVOL/(NU*DELTA*G))**(1./3.)
C---------VISCOUS TO SURFACE TENSION
      TAU2=((K2V/K2T)**2)*(RHOWATR/SIGMA)*(NU*DELTA*G*CCVOL**2)**(1./3.)
C---------SET INITIAL TIME INCREMENT TO TAU1
      TIME=TAU1
      REGIME=1
C---------COMPUTE MAGNITUDE OF SPREAD VECTOR
      CALL SPREAD (REGIME,TIME,S,CCVOL,RHOOIL,RHOWATR,NU,SIGMA,SCALE,
     $ TLAST)
C---------GUESS IS SET EQUAL TO THE ADDRESS OF THE LAST TIDAL POLYGON
C         USED.  IF GUESS=0 THERE IS NO IDEA WHICH ONE TO LOOK AT FIRST
      GUESS=0
C---------COMPUTE CURRENT VECTOR AT TIME  = TAU1
      CALL TIDAL (TIME,OFFSET,XCORD,YCORD,XCV,YCV,POLYGON,NPOLY,
     $ GUESS,TLAST,OFFSHOR)
C---------COMPUTE WIND VECTOR
      CALL VECTOR (WIND(1),XWV,YWV)
      XWV=XWV*WIND(2)
      YWV=YWV*WIND(2)
C---------CALL SUBROUTINE TO COMPUTE DRIFT VECTOR
      CALL DRIFT (XDRIFT,YDRIFT,XWV,YWV,XCV,YCV,TIME,TLAST,OFFSET)
C---------COMPUTE SPREAD AND DRIFT FOR INITIAL 360 POINTS
C---------COMPUTE SPREAD AND DRIFT FOR INITIAL POINTS
      DO 500 I=1,NPOINTS
C---------FIND UNIT NORMAL VECTOR
      THETA=I*360.0/NPOINTS/57.29578
      CALL VECTOR (THETA,XNORM,YNORM)
C---------ADD DRIFT AND SPREAD VECTORS TO POINT COORDINATES,
C         CONVERT TO PLOTTER INCHES
      SLICK(I,1)=SLICK(I,1)+(XDRIFT+S*XNORM)/SCALE/2.54
  500 SLICK(I,2)=SLICK(I,2)+(YDRIFT+S*YNORM)/SCALE/2.54
C---------PLOT GEOGRAPHY
```

```
      CALL GEOPLOT (SITE,HEAD1,HEAD2,XCORD,YCORD)
C--------PRINT HEADINGS FOR OUTPUT
      WRITE (6,70) HEAD1,HEAD2
C--------COMPUTE SPREAD LIMIT
      SLIMIT=10.**5*(CCVOL/100.**3)**0.75
      WRITE (6,535) SLIMIT
  535 FORMAT (1X*SPREAD LIMIT =*F15.0* SQ METERS*/)
      WRITE (6,530)
  530 FORMAT (/1X*ITERATION   CP SECONDS   MODEL TIME   SLICK AREA   NPO
     $INTS   SPREAD   PLOT*/)
      ITR=1
C--------TEST TO SEE IF SLICK SHOULD BE PLOTTED THIS ITERATION
  510 IF (ITR .GT. MAXPLOT) GO TO 513
      DO 511 I=1,40
      IF (NPLOT(I) .EQ. ITR) GO TO 515
  511 CONTINUE
  512 IPLT=1H
      GO TO 525
  513 IF (ITR .LT. MPLOT) GO TO 512
  514 MPLOT=ITR+6
      IF (ITR .EQ. 1) MPLOT=6
  515 IPLT=1HX
C--------PLOT SLICK BOUNDARY
      CALL PLOT (SLICK(1,1),SLICK(1,2),3)
      DO 520 I=2,NPOINTS
  520 CALL PLOT (SLICK(I,1),SLICK(I,2),2)
      CALL PLOT (SLICK(1,1),SLICK(1,2),2)
C--------PRINT OUTPUT
  525 CALL SECOND(T)
      HOURS=TIME/3600.
      IF (ITR .EQ. 1) CALL AREA (XSLICK,YSLICK,NPOINTS,RESULT)
      SAREA=RESULT*SCALE**2*2.54**2/100.**2
      WRITE (6,540) ITR,T,HOURS,SAREA,NPOINTS,S,IPLT
  540 FORMAT (5X,I5,2F13.3,F13.0,I10,F9.0,6X,A1)
C--------SAVE THE SLICK EDGE COORDINATES AND OTHER DATA FOR PLOTTING
C         AT A LATER TIME
      WRITE (2,546) ITR,HOURS,SAREA,NPOINTS,S
  546 FORMAT (I4,F8.3,F10.0,I4,F7.0)
      DO 547 I=1,NPOINTS
```

```
  547 WRITE (2,548) (SLICK(I,J),J=1,2)
  548 FORMAT (2F10.5)
C--------CONTINUE IN SUBSEQUENT TIME PERIODS
      ITR=ITR+1
      TLAST=TIME
      TIME=TIME+DELTAT
C--------TEST FOR END OF RUN (MODEL TIME LIMIT)
      IF (TIME .GT. QUIT) GO TO 730
C--------TEST FOR CP TIME LIMIT
      IF (T .LT. 146.0) GO TO 560
      WRITE (6,550)
  550 FORMAT (//1X*CP TIME LIMIT REACHED*)
      GO TO 730
C--------DETERMINE IF SPREAD LIMIT HAS BEEN REACHED
  560 IF (SAREA .LT. SLIMIT) GO TO 565
      S=0.
      GO TO 570
C--------DETERMINE SPREAD REGIME
  565 REGIME=2
      IF (TLAST .LT. TAU2 .AND. TIME .GT. TAU2) TIME=TAU2
      IF (TIME .GT. TAU2) REGIME=3
C--------COMPUTE SPREAD MAGNITUDE
      CALL SPREAD (REGIME,TIME,S,CCVOL,RHOOIL,RHOWATR,NU,SIGMA,SCALE,
     $TLAST)
C--------THE FOLLOWING SEQUENCE TESTS THE POINTS ON THE SLICK BOUNDARY
C        AND ADDS NEW POINTS IF ANY TWO OF THEM ARE OVER 1/4 INCH
C        (MAP SCALE) APART
C--------SKIP THIS SEQUENCE ON THE FIRST ITERATION
  570 IF (ITR .LE. 2) GO TO 680
C--------NO NEW POINTS CAN BE ADDED IF THE SLICK EDGE ARRAY IS FULL
      IF (NPOINTS .GE. 100) GO TO 680
C--------IF ITEST = 1, TWO POINTS HAVE BEEN FOUND THAT ARE OVER 1/4
C        INCH APART
      ITEST=0
C--------NADD COUNTS THE NUMBER OF ITERATIONS THROUGH THIS SEQUENCE
      NADD=0
  575 NADD=NADD+1
      IF (NADD .GT. 1 .AND. ITEST .EQ. 0) GO TO 680
C--------RESET ITEST FOR NEXT ITERATION
```

```
      IF (ITEST .EQ. 1) ITEST=0
C--------N IS THE POINT NUMBER IN THE ARRAY
      N=0
  580 N=N+1
      IF (N .GT. NPOINTS) GO TO 575
      IF (N .GT. 1) GO TO 590
C--------COMPUTE DISTANCE BETWEEN TWO POINTS
      DIST=SQRT((SLICK(1,1)-SLICK(NPOINTS,1))**2
     $ +(SLICK(1,2)-SLICK(NPOINTS,2))**2)
      GO TO 600
  590 DIST=SQRT((SLICK(N,1)-SLICK(N-1,1))**2
     $ +(SLICK(N,2)-SLICK(N-1,2))**2)
C--------TEST THE DISTANCE BETWEEN POINTS
  600 IF (DIST .LT. .25) GO TO 580
C--------POINTS OVER 1/4 INCH APART HAVE BEEN FOUND
      ITEST=1
C--------ALLOW ONLY 2 ITERATION THROUGH THE ROUTINE
      IF (NADD .GT. 2) GO TO 560
C--------TEST TO SEE IF POINT ARRAY IS FULL
      IF (NPOINTS .GE. 100) GO TO 630
C--------ADD A NEW POINT
      NPOINTS=NPOINTS+1
C--------MOVE ALL THE POINTS UP ONE POSITION IN THE ARRAY
      J=NPOINTS-N
      DO 610 I=1,J
      K=NPOINTS-I+1
      SLICK(K,1)=SLICK(K-1,1)
      SLICK(K,2)=SLICK(K-1,2)
  610 SLICK(K,3)=SLICK(K-1,3)
      IF (N .GT. 1) GO TO 620
C--------DETERMINE THE COORDINATES OF A NEW POINT HALF WAY BETWEEN THE
C         OLD ONES
      SLICK(N,1)=SLICK(NPOINTS,1)+(SLICK(N+1,1)-SLICK(NPOINTS,1))/2.
      SLICK(N,2)=SLICK(NPOINTS,2)+(SLICK(N+1,2)-SLICK(NPOINTS,2))/2.
      SLICK(N,3)=0.
      GO TO 580
  620 SLICK(N,1)=SLICK(N-1,1)+(SLICK(N+1,1)-SLICK(N-1,1))/2.
      SLICK(N,2)=SLICK(N-1,2)+(SLICK(N+1,2)-SLICK(N-1,2))/2.
      SLICK(N,3)=0.
```

```
      GO TO 580
C--------ALL 100 POINTS HAVE BEEN USED FOR THE SLICK BOUNDARY
  630 WRITE (6,640) ITR
  640 FORMAT (/1X*THE MAXIMUM NUMBER OF POINTS (100) ARE ALL READY IN TH
     $E SLICK ARRAY AS OF ITERATION*I5/1X*NO NEW POINTS WILL BE ADDED*/)
      GO TO 680
  660 WRITE (6,670)
  670 FORMAT (/1X*POINTS ARE STILL OVER 1/4 INCH APART AFTER 2 ITERATION
     $S*/)
C--------INITIALIZE ACCUMULATORS FOR COMPUTING AVERAGE SLICK MOVEMENT
  680 XAVG=0.
      YAVG=0.
C--------COMPUTE SPREAD AND DRIFT FOR ALL POINTS
      DO 720 I=1,NPOINTS
C--------NO NEED TO COMPUTE THE UNIT NORMAL VECTOR IF THE SPREAD
C           MAGNITUDE IS ZERO
      IF (S .GT. 0.) GO TO 685
      XNORM=0.
      YNORM=0.
      GO TO 716
C--------COMPUTE UNIT VECTOR NORMAL TO SLICK EDGE AT EACH POINT
  685 IF (I .GT. 1) GO TO 690
      XLAST=SLICK(NPOINTS,1)
      YLAST=SLICK(NPOINTS,2)
      XN=SLICK(1,1)
      YN=SLICK(1,2)
      GO TO 710
  690 IF (I .LT. NPOINTS) GO TO 700
      XNEXT=XN
      YNEXT=YN
      XLAST=XL
      YLAST=YL
      GO TO 715
  700 XLAST=XL
      YLAST=YL
  710 XNEXT=SLICK(I+1,1)
      YNEXT=SLICK(I+1,2)
      XL=SLICK(1,1)
      YL=SLICK(I,2)
```

```
C--------DETERMINE CLOCKWISE VECTOR BETWEEN POINTS ON BOTH SIDES OF THE
C            ONE IN QUESTION
   715 X=XNEXT-XLAST
       Y=YNEXT-YLAST
C--------DETERMINE CORRESPONDING UNIT VECTOR (Y ONLY)
       Y=Y/SQRT(X**2+Y**2)
C--------COMPUTE THE ANGLE BETWEEN THE VECTOR AND THE Y-AXIS
       THETA=ACOS(Y)
C--------ADJUST THETA FOR PROPER QUADRANT AFTER ARC-COSINE FUNCTION
       IF (X .LT. 0.) THETA=2.*PI-THETA
C--------SUBTRACT 90 DEG (PI/2) TO OBTAIN THE VECTOR NORMAL TO THE SLICK
       THETA=THETA-PI/2.
       CALL VECTOR (THETA,XNORM,YNORM)
C--------COMPUTE CURRENT VECTOR AT EACH POINT
   716 CONTINUE
       CALL TIDAL (TIME,OFFSET,SLICK(I,1),SLICK(I,2),XCV,YCV,POLYGON,
      $ NPOLY,GUESS,TLAST,OFFSHOR)
C--------COMPUTE DRIFT VECTOR
       CALL DRIFT (XDRIFT,YDRIFT,XWV,YWV,XCV,YCV,TIME,TLAST,OFFSET)
C--------ACCUMULATE DRIFT VECTORS FOR COMPUTING AVERAGE SLICK MOVEMENT
       XAVG=XAVG+XDRIFT
       YAVG=YAVG+YDRIFT
C--------ADD SPREAD (IN PLOTTER INCHES) TO EACH POINT ON THE VIRTUAL
C            SLICK EDGE
       XVIRT(I)=SLICK(I,1)+S*XNORM/SCALE/2.54
       YVIRT(I)=SLICK(I,2)+S*YNORM/SCALE/2.54
C--------ADD DRIFT AND SPREAD VECTORS TO COORDINATES OF EACH POINT,
C            CONVERT TO PLOTTER INCHES
       SLICK(I,1)=SLICK(I,1)+(XDRIFT+S*XNORM)/SCALE/2.54
   720 SLICK(I,2)=SLICK(I,2)+(YDRIFT+S*YNORM)/SCALE/2.54
C--------COMPUTE THE AVERAGE DRIFT VECTORS FOR ALL POINTS ON THE SLICK
       XAVG=XAVG/NPOINTS/SCALE/2.54
       YAVG=YAVG/NPOINTS/SCALE/2.54
C--------ADD THE AVERAGE DRIFT TO ALL POINTS ON THE VIRTUAL SLICK
       DO 721 I=1,NPOINTS
       XVIRT(I)=XVIRT(I)+XAVG
   721 YVIRT(I)=YVIRT(I)+YAVG
C--------SAVE THE NUMBER OF VIRTUAL POINTS SINCE NPOINTS WILL CHANGE
       NPVIRT=NPOINTS
```

```
C--------THE FOLLOWING SEQUENCE ELIMINATES LOOPS OR OVERLAPS IN THE
C          SLICK EDGE BY PLACING A TEST POINT A SMALL DISTANCE (EPS)
C          OUTSIDE OF EACH ARRAY POINT AND TESTING TO SEE IF THE TEST
C          POINT IS IN THE SLICK POLYGON
      DO 726 I=1,NPOINTS
C--------COMPUTE UNIT VECTOR NORMAL TO SLICK EDGE AT EACH POINT
      IF (I .GT. 1) GO TO 722
      XLAST=SLICK(NPOINTS,1)
      YLAST=SLICK(NPOINTS,2)
      XN=SLICK(1,1)
      YN=SLICK(1,2)
      GO TO 724
  722 IF (I .LT. NPOINTS) GO TO 723
      XNEXT=XN
      YNEXT=YN
      XLAST=XL
      YLAST=YL
      GO TO 725
  723 XLAST=XL
      YLAST=YL
  724 XNEXT=SLICK(I+1,1)
      YNEXT=SLICK(I+1,2)
      XL=SLICK(I,1)
      YL=SLICK(I,2)
C--------DETERMINE CLOCKWISE VECTOR BETWEEN POINTS ON BOTH SIDES OF THE
C          ONE IN QUESTION
  725 X=XNEXT-XLAST
      Y=YNEXT-YLAST
C--------DETERMINE CORRESPONDING UNIT VECTOR (Y ONLY)
      Y=Y/SQRT(X**2+Y**2)
C--------COMPUTE THE ANGLE BETWEEN THE VECTOR AND THE Y-AXIS
      THETA=ACOS(Y)
C--------ADJUST THETA FOR PROPER QUADRANT AFTER ARC-COSINE FUNCTION
      IF (X .LT. 0.) THETA=2.*PI-THETA
C--------SUBTRACT 90 DEG (PI/2) TO OBTAIN THE VECTOR NORMAL TO THE SLICK
      THETA=THETA-PI/2.
      CALL VECTOR (THETA,XNORM,YNORM)
C--------ESTABLISH A TEST POINT AT A DISTANCE (EPS) AND IN THE
C          DIRECTION NORMAL TO THE SLICK EDGE OUTWARD
```

```
C---------THIS WILL TEST FOR INSIDE LOOPS
      XTEST=SLICK(I,1)+XNORM*EPS
      YTEST=SLICK(I,2)+YNORM*EPS
C---------TEST TO SEE IF TEST POINT IS IN THE SLICK POLYGON
      M=NPOINTS+1
      SLICK(M,1)=SLICK(1,1)
      SLICK(M,2)=SLICK(1,2)
      CALL CAUCH (XSLICK,YSLICK,NPOINTS,M,XTEST,YTEST,IN,XDUMY,YDUMY,ND)
C---------FLAG THE ARRAY POINT IF THE TEST POINT IS IN THE SLICK POLYGON
      IF (IN) SLICK(I,3)=-1.0
C---------ESTABLISH A TEST POINT AT A DISTANCE (EPS) AND IN THE
C         DIRECTION NORMAL TO THE SLICK EDGE INWARD
C---------THIS WILL TEST FOR OUTSIDE LOOPS
      XTEST=SLICK(I,1)-XNORM*EPS
      YTEST=SLICK(I,2)-YNORM*EPS
C---------TEST TO SEE IF THE POINT IS IN THE SLICK POLYGON
      CALL CAUCH (XSLICK,YSLICK,NPOINTS,M,XTEST,YTEST,IN,XDUMY,YDUMY,ND)
C---------FLAG THE ARRAY POINT IF THE TEST POINT IS OUTSIDE THE SLICK
C         POLYGON
      IF (.NOT. IN) SLICK(I,3)=-1.0
  726 CONTINUE
C---------ELIMINATE ALL FLAGGED POINTS IN THE SLICK ARRAY
      N=0
  727 N=N+1
C---------CONTINUE NEXT TIME PERIOD IF ALL POINTS HAVE BEEN TESTED
      IF (N .GT. NPOINTS) GO TO 731
C---------TEST FOR FLAG (-1)
  729 IF (SLICK(N,3) .GT. -.5) GO TO 727
C---------DECREASE NUMBER OF POINTS BY ONE
      NPOINTS=NPOINTS-1
C---------LAST POINT IS A SPECIAL CASE
      IF (N .GT. NPOINTS) GO TO 731
C---------MOVE ALL THE POINTS UP ONE INDEX
      DO 728 I=N,NPOINTS
      SLICK(I,1)=SLICK(I+1,1)
      SLICK(I,2)=SLICK(I+1,2)
  728 SLICK(I,3)=SLICK(I+1,3)
      GO TO 729
  731 CONTINUE
```

```
C---------COMPUTE THE AREAS OF THE REAL AND VIRTUAL SLICKS
          CALL AREA (XSLICK,YSLICK,NPOINTS,RESULT)
          CALL AREA (XVIRT,YVIRT,NPVIRT,RESULTV)
C---------COMPARE THE AREAS, CONTINUE WITH THE LARGEST
          IF (RESULT .GE. RESULTV) GO TO 510
C---------SUBSTITUTE THE VIRTUAL SLICK FOR THE REAL SLICK
          DO 732 I=1,NPVIRT
          IF (SLICK(I,3) .LT. -.5) SLICK(I,3)=0.
          SLICK(I,1)=XVIRT(I)
      732 SLICK(I,2)=YVIRT(I)
          NPOINTS=NPVIRT
          RESULT=RESULTV
          GO TO 510
C---------EXIT ROUTINE
      730 CONTINUE
          CALL PLOT (0.,0.,999)
          ENDFILE 2
          WRITE (6,740)
      740 FORMAT (1H1*END OF RUN*)
          STOP
          END
```

```
      SUBROUTINE SPREAD (REGIME,TIME,S,CCVOL,RHOOIL,RHOWATR,NU,SIGMA,
     $ SCALE,TLAST)
      INTEGER REGIME
      REAL NU,K2I,K2V,K2T
C---------INITIALIZE CONSTANTS
      G=980.7
      K2I=1.14
      K2V=1.45
      K2T=2.05
C---------COMPUTE DENSITY RATIO
      DELTA=1.-RHOOIL/RHOWATR
C---------BRANCH ON TIME REGIME
C        REGIME = 1  INERTIAL
C        REGIME = 2  VISCOUS
C        REGIME = 3  SURFACE TENSION
      GO TO (20,30,40),REGIME
C---------INERTIAL REGIME  (S IS IN CENTEMETERS)
   20 S=K2I*(DELTA*G*CCVOL*TIME**2)**(1./4.)
     $ -K2I*(DELTA*G*CCVOL*TLAST**2)**(1./4.)
      RETURN
C---------VISCOUS REGIME
   30 S=K2V*(DELTA*G*CCVOL**2*TIME **1.5/NU**0.5)**(1./6.)
     $ -K2V*(DELTA*G*CCVOL**2*TLAST**1.5/NU**0.5)**(1./6.)
      RETURN
C---------SURFACE TENSION REGIME
   40 S=K2T*(SIGMA**2*TIME **3/RHOWATR**2/NU)**0.25
     $ -K2T*(SIGMA**2*TLAST**3/RHOWATR**2/NU)**0.25
      RETURN
      END
```

```
      SUBROUTINE TIDAL (TIME,OFFSET,XPOINT,YPOINT,XCV,YCV,POLYGON,NPOLY,
     $ GUESS,TLAST,OFFSHOR)
C--------THIS SUBROUTINE TESTS ANY POINT (XPOINT,YPOINT) TO SEE IF IT IS
C        IN ONE OF THE TIDAL POLYGONS AND RETURNS THE CURRENT VECTOR
C        (XCV+YCV) IN CENTEMETERS PER SECOND
C--------POLYGON IS THE ARRAY OF TIDAL POLYGONS (MAX=20)  THE 21ST
C        POLYGON IS THE DEFAULT CURRENT
C--------AT TIME = 0 (TIME OF SPILL) THE TIDE IS ASSUMED TO BE AT SLACK
C        BEFORE EBB.  THIS CONDITION CAN BE MODIFIED BY OFFSET WHICH
C        ADVANCES THE STARTING TIME FOR COMPUTATION BY A GIVEN AMOUNT
C        OF TIME
C--------GUESS IS AN ATTEMPT TO SAVE COMPUTER TIME BY ASSUMING THAT
C        A GIVEN POINT WILL BE IN THE SAME POLYGON AS THE LAST POINT.
C        THE ADDRESS OF THE LAST SUCCESSFUL POLYGON TEST WILL BE TRIED
C        FIRST
C--------IF THE VARIABLE (OFFSHOR) IS NOT BLANK, IT IS ASSUMED THAT
C        THE RUN IS FOR AN OFFSHORE SITE AND THERE IS NO EBB OR FLOOD
      LOGICAL IN
      INTEGER GUESS,OFFSHOR
      REAL POLYGON(21,12),XX(5),YY(5),D1(5),D2(5)
      PI=3.14159
C--------TEST FOR OFFSHORE CONDITIONS (NO EBB OR FLOOD)
      IF (OFFSHOR .EQ. 1H ) GO TO 10
C--------OFFSHORE CONDITIONS
      GUESS=0
C--------CONVERT DEFAULT TIDE DIRECTION TO A UNIT VECTOR
      THETA=POLYGON(21,1)/57.2957795
      CALL VECTOR (THETA,XCV,YCV)
C--------COMPUTE MAGNITUDE OF CURRENT VECTOR
      CVMAG=POLYGON(21,2)*(TIME-TLAST)
      GO TO 60
C--------EBB AND FLOOD CONDITIONS (ON-SHORE)
   10 I=GUESS
C--------IF THE VALUE OF GUESS IS ZERO, THERE IS NO OPINION
      IF (GUESS .GT. 0) GO TO 30
   20 I=I+1
   30 IF (I .GT. NPOLY) GO TO 40
C--------SET UP ARRAY OF VERTICES
      XX(1)=POLYGON(I,5)
```

```
      XX(2)=POLYGON(I,7)
      XX(3)=POLYGON(I,9)
      XX(4)=POLYGON(I,11)
      XX(5)=XX(1)
      YY(1)=POLYGON(I,6)
      YY(2)=POLYGON(I,8)
      YY(3)=POLYGON(I,10)
      YY(4)=POLYGON(I,12)
      YY(5)=YY(1)
C--------FIND VERTICES OF ENCLOSING RECTANGLE
      XMAX=0.
      YMAX=0.
      XMIN=100.
      YMIN=100.
      DO 35 K=1,4
      IF (XX(K) .GE. XMAX) XMAX=XX(K)
      IF (YY(K) .GE. YMAX) YMAX=YY(K)
      IF (XX(K) .LE. XMIN) XMIN=XX(K)
      IF (YY(K) .LE. YMIN) YMIN=YY(K)
   35 CONTINUE
C--------TEST FOR POINT IN ENCLOSING RECTANGLE
      CALL CART (XPOINT,YPOINT,XMIN,YMIN,XMAX,YMAX,IN)
      IF (.NOT. IN) GO TO 38
C--------TEST FOR POINT IN TIDAL POLYGON
      CALL CAUCH (XX,YY,4,5,XPOINT,YPOINT,IN,D1,D2,IDUMY)
C--------IF THE POINT IS IN THE POLYGON, IN = .TRUE.
      IF (IN) GO TO 50
C--------POINT IS NOT IN THE POLYGON
   38 IF (GUESS .EQ. 0) GO TO 20
C--------IF THE GUESS WAS NOT CORRECT, CHECK ALL THE POLYGONS IN ORDER
      GUESS=0
      GO TO 10
C--------POINT WAS NOT IN ANY POLYGON,  USE DEFAULT CURRENT
   40 I=21
      GUESS=0
C--------IF THE POINT IS IN THE POLYGON, TEST FOR EBB OR FLOOD
   50 IF (I .LT. 21) GUESS=I
      PHI=(TIME+OFFSET)/3600.*PI/6.
      PHILAST=(TLAST+OFFSET)/3600.*PI/6.
```

```
      TIDE=SIN(PHI)
      J=1
      IF (TIDE .GT. 0.) J=3
C--------DETERMINE DIRECTION AND CURRENT FACTOR
      THETA=POLYGON(I,J)/57.2957795
      FACTOR=POLYGON(I,J+1)
      IF (I .EQ. 21) FACTOR=1.0
C--------CONVERT TIDE DIRECTION TO A UNIT VECTOR
      CALL VECTOR (THETA,XCV,YCV)
C--------COMPUTE MAGNITUDE OF TIDAL VECTOR (CM) INTEGRATED OVER
C         TLAST TO TNOW (TIME)
      CVMAG=FACTOR*POLYGON(21,J+1)*21600./PI*ABS(COS(PHILAST)-COS(PHI))
C--------COMPUTE X AND Y COMPONENTS OF CURRENT VECTOR
   60 XCV=XCV*CVMAG
      YCV=YCV*CVMAG
      RETURN
      END
```

```
      SUBROUTINE DRIFT (XDRIFT,YDRIFT,XWV,YWV,XCV,YCV,TIME,TLAST,OFFSET)
C--------THIS SUBROUTINE COMPUTES THE DRIFT OF POINTS ON THE EDGE OF
C          THE OIL SLICK DUE TO WIND AND TIDAL CURRENT ACTION

      PI=3.14159
C--------COMPUTE BETA
      BETA=SQRT(XWV**2+YWV**2)
C--------TEST FOR THE ZERO WIND CONDITION
      IF (BETA .GT. 0.) GO TO 10
C--------IF THERE IS NO WIND, DRIFT IS EQUAL TO THE CURRENT VECTOR
      XDRIFT=XCV
      YDRIFT=YCV
      RETURN
C--------COMPUTE ALPHA
   10 ALPHA=(XCV*XWV+YCV*YWV)/BETA
C--------COMPUTE THE CURRENT DRIFT PARALLEL TO THE WIND VECTOR
      XCPARAL=ALPHA*XWV/BETA
      YCPARAL=ALPHA*YWV/BETA
C--------COMPUTE THE CURRENT DRIFT PERPENDICULAR TO THE WIND VECTOR
      XCPERP=XCV-XCPARAL
      YCPERP=YCV-YCPARAL
C--------COMPUTE X-COMPONENT OF DRIFT VECTOR
      XDRIFT=0.031*XWV*(TIME-TLAST)+0.56*XCPARAL+XCPERP
C--------COMPUTE Y-COMPONENT OF DRIFT VECTOR
      YDRIFT=0.031*YWV*(TIME-TLAST)+0.56*YCPARAL+YCPERP
      RETURN
      END
```

```
      SUBROUTINE GEOPLOT (SITE,HEAD1,HEAD2,XCORD,YCORD)

C--------THIS SUBROUTINE PLOTS THE SITE GEOGRAPHY, THE TEN FATHOM CURVE,
C         THE BORDERS, THE HEADINGS, AND THE SLICK ORIGIN

C--------IT ASSUMES THAT THE PLOT HAS BEEN  INITIALIZED AND THE ORIGIN
C         IS PROPERLY PLACED BY THE MAIN PROGRAM

      INTEGER NAME(2),SITE(2),HEAD1(8),HEAD2(8),CODE,WATER
      REAL XX(4),YY(4)
C--------REWIND THE SITE TAPE
      REWIND 1
C--------READ THE FIRST FOUR RECORDS (CORNERS)
      DO 20 I=1,4
      READ (1,10) XX(I),YY(I),NAME
   10 FORMAT (14X,2F5.0,1X,A10,A2)
C--------CONVERT DIGITIZER UNITS TO INCHES
      XX(I)=XX(I)/250.
   20 YY(I)=YY(I)/250.
C--------TEST FOR CORRECT SITE TAPE
      IF (NAME(1) .EQ. SITE(1) .AND. NAME(2) .EQ. SITE(2)) GO TO 40
      WRITE (6,30) NAME,SITE
   30 FORMAT (1H1*YOU ARE USING THE WRONG SITE TAPE*//1X*SITE TAPE = *
     $ A10,A2/1X*SITE NAME = *A10,A2//1X*CRASH*)
      STOP
C--------PLOT BOUNDARIES
   40 DO 50 I=2,4
   50 CALL PLOT (XX(I),YY(I),2)
      CALL PLOT(XX(1),YY(1),2)
C--------PLOT HEADINGS
      Y=YY(2)+1.0
      CALL SYMBOL (0.,Y,.35,HEAD1,0.,80)
      Y=Y-.5
      CALL SYMBOL (0.,Y,.35,HEAD2,0.,80)
C--------PLOT SHORE LINES
      LAST=1H3
   60 READ (1,70) CODE,WATER,X,Y
   70 FORMAT (A1,3X,A2,8X,2F5.0)
      IF (EOF,1) 110,30
```

```
C--------CONVERT UNITS
   80 X=X/250.
      Y=Y/250.
C--------IGNORE SPILL LOCATION IF CODED
      IF (WATER .EQ. 2HSP) GO TO 60
C--------TEST FOR BREAKS IN SHORELINE (CODE=B)
C--------RAISE THE PEN BETWEEN BREAKS
      IC=2
      IF (CODE .EQ. 1HB .AND. LAST .EQ. 1HB) IC=3
C--------TEST FOR WATER (PLOT WITH DASHED LINES)
      IF (IC .EQ. 2 .AND. WATER .EQ. 2HWA) GO TO 90
      CALL PLOT (X,Y,IC)
      GO TO 100
C--------PLOT DASHED 10 FATHOM CURVE
   90 CALL SYMBOL (X,Y,.024,3,0.,-1)
  100 LAST=CODE
      GO TO 60
C--------PLOT OIL SPILL ORIGIN
  110 CALL SYMBOL (XCORD,YCORD,.5,3,0.,-1)
      RETURN
      END
```

```
      SUBROUTINE VECTOR (THETA,I,J)
C--------THIS SUBROUTINE CONVERTS ANY ANGLE THETA, MEASURED IN RADIANS
C           FROM THE Y-AXIS (NORTH) INTO THE CORRESPONDING UNIT VECTOR
C           (I + J)
      REAL I,J
C--------COMPUTE I
      I=SIN(THETA)
C--------COMPUTE J
      J=COS(THETA)
      RETURN
      END
```

```
      SUBROUTINE AREA(X,Y,N,RESULT)
C--------THIS SUBROUTINE CALCULATES THE AREA OF A TWO
C--------DIMENSIONAL POLYGON OF N VERTICES.
C--------THE POLYGONS COORDINATES ARE TO BE PROVIDED
C--------IN ARRAYS X AND Y, EACH OF DIMENSION N
C--------AREA WILL BE RETURNED IN RESULT
      REAL X(N),Y(N)
C--------THE ANALYSIS PER URBAN DATA CENTER DOCUMENT
C--------PB 219 671, PAGE 22 YIELDS THE FOLLOWING RESULT
C--------
C--------AREA = 1/2 * SUM OF (CROSS PRODUCTS OF ALL ADJACENT
C--------VERTICE PAIRS)
C--------CALCULATE THE CROSS PRODUCTS AND SUM
      ISUB = N-1
      SUM = 0.0
      DO 50 I = 1,ISUB
      SUM = SUM + X(I) * Y(I+1) - X(I+1) * Y(I)
   50 CONTINUE
      SUM = SUM + X(N) * Y(1) - X(1) * Y(N)
C--------COMPLETE AREA CALCULATION.  DEPENDING ON THE PATH CHOSEN
C--------AROUND THE POLYGON, WE COULD HAVE A NEGATIVE AREA.
      RESULT = 0.5 * ABS(SUM)
      RETURN
      END
```

```
      SUBROUTINE CART(X0,Y0,X1,Y1,X3,Y3,INTR)
C---------CARTESIAN RECTANGLE
      LOGICAL INTR
C---------THIS SUBROUTINE DETERMINES WHETHER THE GIVEN POINT (X0,Y0) IS
C---------INTERIOR TO THE GIVEN RECTANGLE.
C---------(X1,Y1) AND (X3,Y3) ARE VERTICES ON A DIAGONAL OF THE RECTANGLE.
C---------INTR IS SET TO TRUE IF (X0,Y0) IS INTERIOR - FALSE IF IT IS EXTERIOR.
C---------X0,X1,X3,Y3,Y1,Y3 ARE ASSUMED TO BE REAL NUMBERS.
      INTR = .TRUE.
      IF (X1-X0) 10,15,25
   10 IF (X3-X0) 25,15,15
   15 IF (Y1-Y0) 20,30,25
   20 IF (Y3-Y0) 25,30,30
   25 INTR = .FALSE.
   30 RETURN
      END
```

```
      SUBROUTINE CAUCH(XX,YY,NN,M,X0,Y0,INTR,X,Y,ISUB)
C---------COMBINATURIAL CAUCHY   (THE DIAMOND)
C---------THIS SUBROUTINE FIRST IMAGINES A DIAMOND ABOUT THE POINT (X0,Y0)
C---------GIVEN AN ORIENTAITON COUNTERCLOCKWISE.  THEN IT SUMS UP THE NUMBER
C---------OF TIMES EACH SIDE OF THE POLYGON INTERSECTS THE AXES ABOUT
C---------(X0,Y0) AS THE ORIGIN.  THIS NUMBER IS GIVEN A SIGN + OR -
C---------DEPENDING ON WHETEHER IT CROSSES IN THE POSITIVE OR NEGATIVE
C---------DIRECTION OF THE ORIENTATION OF THE DIAMOND.  IF THE SUM IS
C---------NOT ZERO, THEN THE POINT IN QUESTION Z0=(X0,Y0) IS INTERIOR AND
C---------INTR WILL BE SET TO TRUE.  OTHERWISE Z0 IS EXTERIOR AND INTR
C---------WILL BE FALSE.
C---------INPUT IS AS FOLLOWS
C---------NN IS THE (INTEGRAL) NUMBER OF VERTICES IN THE POLYGON.
C---------XX,YY ARE THE (REAL) ARRAYS CONTAINING THE VERTICES OF THE POLYGON
C---------IN THE GIVEN ORIENTATION...(XX(J),YY(J))=Z(J), THE JTH VERTEX,
C---------ALSO MUST HAVE Z(NN+1) = Z(1).
C---------X0,Y0 IS THE (REAL) POINT IN QUESTION.
C---------THE ARRAYS X AND Y MUST BE DIMENSIONED LARGE ENOUGH
C---------TO ACCOMMODATE THE SAME NUMBER OF VERTICES AS IN THE POLYGON.
      LOGICAL INTR
      INTEGER QUAD
      REAL LAMDA
      DIMENSION X(M),Y(M),XX(M),YY(M)
      INTR = .FALSE.
      DISTM = +1.0E+322
C---------TRANSLATE VERTICES OF POLYGON WITH RESPECT TO (X0,Y0) AS THE ORIGIN
      DO 20 J = 1,M
      X(J) = XX(J) - X0
   20 Y(J) = YY(J) - Y0
      ISUM = 0
      DO 100 J = 1,NN
C---------DETERMINE WHICH QUADRANTS THE VERTICES Z(J) AND Z(J+1) LIE
C---------IN.  Z(J) WILL LIE IN QUADRANT IQ1, Z(J+1) IN IQ2.
      IQ1 = QUAD(X(J),Y(J))
      IQ2 = QUAD(X(J+1),Y(J+1))
      IF (IQ1 .GE. 4) GO TO 111
      IF (IQ2 .GE. 4) GO TO 111
C---------ARE THE VERTICES IN THE SAME QUADRANT.  IF SO, THERE ARE NO
C---------CROSSINGS OF QUADRANT LINES
```

```
   30    IF (IQ2 - IQ1 ) 50,100,31
C--------VERTICES ARE IN DIFFERENT QUADRANTS - IF THEY ARE IN ADJACENT
C--------QUADRANTS, DETERMINE THE ORIENTATION OF THE CROSSING.
   31    IF (IQ2 - 1 - IQ1) 160,33,35
C--------CROSSING OF RAY IN POSITIVE DIRECTION
   33    ISUM = ISUM + 1
         GO TO 90
   35    IF (IQ1) 160,36,38
   36    IF (IQ2 - 3) 45,37,160
C--------CROSSING OF RAY IN NEGATIVE DIRECTION...QUAD 0 TO QUAD 3
   37    ISUM = ISUM - 1
         GO TO 90
C--------CHECK FOR TWO CROSSINGS IN NEGATIVE OR POSITIVE DIRECTION -
C--------EITHER FROM QUAD 1 TO QUAD 2 TO QUAD 3 OR
C--------FROM QUAD 1 TO QUAD 0 TO QUAD 3
   38    CALL INTER(X(J),Y(J),X(J+1),Y(J+1),LAMDA)
         IF (LAMDA) 42,165,40
C--------TWO NEGATIVE CROSSINGS
   40    ISUM = ISUM - 2
         GO TO 90
C--------TWO POSITIVE CROSSINGS
   42    ISUM = ISUM + 2
         GO TO 90
C--------CHECK FOR TWO CROSSINGS IN THE NEGATIVE DIRECTION -
C--------EITHER FROM QUAD 0 TO QUAD 3 TO QUAD 2, OR IN THE POSITIVE DIRECTION
C--------FROM QUAD 0 TO QUAD 1 TO QUAD 2
   45    CALL INTER(X(J),Y(J),X(J+1),Y(J+1),LAMDA)
         IF (LAMDA) 48,165,46
C--------TWO CROSSINGS IN NEGATIVE DIRECTION
   46    ISUM = ISUM - 2
         GO TO 90
C--------TWO CROSSINGS IN POSITIVE DIRECTION
   48    ISUM = ISUM + 2
         GO TO 90
C--------VERTICES ARE IN DIFFERENT QUADRANTS, DETERMINE ORIENTATION CROSSINGS.
   50    IF (IQ2 + 1 - IQ1) 53,51,160
C--------CROSSING OF RAY IN NEGATIVE DIRECTION
   51    ISUM = ISUM - 1
         GO TO 90
```

```
 53     IF (IQ2) 160,54,65
 54     IF (3 - IQ1) 160,55,57
C--------CROSSING IN POSITIVE DIRECTION
 55     ISUM = ISUM + 1
        GO TO 90
C--------LAST VERTEX IS ZERO CHECK ORIENTATION OF TWO CROSSINGS...
C--------EITHER FROM QUAD 2 TO QUAD 3 TO QUAD 0 OR
C--------FROM QUAD 2 TO QUAD 1 TO QUAD 0.
 57     CALL INTER(X(J),Y(J),X(J+1),Y(J+1),LAMDA)
        IF (LAMDA) 60,165,64
C--------TWO NEGATIVE CROSSINGS
 60     ISUM = ISUM - 2
        GO TO 90
C--------TWO POSITIVE CROSSINGS
 64     ISUM = ISUM + 2
        GO TO 90
C--------CHECK ORIENTATION FOR TWO CROSSINGS,NEGATIVE DIRECTION IF
C--------IT TRAVELS FROM QUAD 3 TO QUAD 2 TO QUAD 1, OR POSITIVE IF
C--------IT TRAVELS FROM QUAD 3 TO QUAD 0 TO QUAD 1.
 65     CALL INTER(X(J),Y(J),X(J+1),Y(J+1),LAMDA)
        IF (LAMDA) 67,165,69
C--------TWO CROSSINGS IN NEGATIVE DIRECTION
 67     ISUM = ISUM - 2
        GO TO 90
C--------TWO CROSSINGS IN POSITIVE DIRECTION
 69     ISUM = ISUM + 2
C--------HERE IF WE HAD A CROSSING
 90     DIST1 = SQRT(X(J)**2 + Y(J) **2)
        DIST2 = SQRT(X(J+1)**2 + Y(J+1) **2)
        DISTM = AMIN1(DISTM,DIST1,DIST2)
        IF (DISTM .EQ. DIST1) ISUB = J
        IF (DISTM .EQ. DIST2) ISUB = J + 1
C--------RETURN ISUB,THE SUBSCRIPT OF THE OIL SLICK POINT
C--------CLOSEST TO THE INTERIOR POINT
C--------
 100    CONTINUE
        IF (ISUM .EQ. 0) GO TO 102
C--------Z0 IS INTERIOR
        INTR = .TRUE.
```

```
C--------Z0 IS EXTERIOR
C--------
  102 RETURN
C--------THE FOLLOWING ARE SPECIAL MESSAGES
  111 WRITE (6,112) X0,Y0
  112 FORMAT(*0*,2F10.3,* IS A VERTEX*)
      IF (IQ1 .GE. 4) ISUB = J
      IF (IQ2 .GE. 4) ISUB = J + 1
      INTR = .TRUE.
      RETURN
C--------
  160 WRITE (6,161) IQ1,IQ2
  161 FORMAT(*0ILLEGAL QUADRANT NUMBERS*,2I6)
      RETURN
C--------
  165 WRITE (6,166) X0,Y0
  166 FORMAT(* *,2F10.3,* IS ON THE BOUNDARY*)
      DIST1 = SQRT(X(J)**2 + Y(J) **2)
      DIST2 = SQRT(X(J+1)**2 + Y(J+1) **2)
      DISTM = AMIN1(DISTM,DIST1,DIST2)
      IF (DISTM .EQ. DIST1) ISUB = J
      IF (DISTM .EQ. DIST2) ISUB = J + 1
      INTR = .TRUE.
      RETURN
      END
```

```
      SUBROUTINE INTER(X1,Y1,X2,Y2,LAM)
      REAL LAM
C--------LAM CONTAINS THE VALUE OF THE X COORDINATE
      LAM = 0.0
      DIFF = Y1 - Y2
      IF (DIFF) 10,100,10
 10   T = Y1 / DIFF
C--------T MUST BE BETWEEN 0 AND 1
      IF (T .LT. 0 .OR. T .GT. 1.) GO TO 50
C--------CALCULATE X INTERCEPT
      LAM = (1. - T) * X1 + T * X2
      RETURN
C--------SIDE DOES NOT INTERSECT X-AXIS
 50   WRITE (3,51) X1,Y1,X2,Y2
 51   FORMAT(*0POLYGON SIDE FROM (X,Y)*,2F10.4,* TO (X,Y)*,
     12F10.4,*DOES NOT INTERSECT X-AXIS*)
      RETURN
C--------NO SOLUTION, Y-COORDINATES ARE THE SAME
 100  WRITE (3,101) X1,Y1,X2,Y2
 101  FORMAT(*0NO SOLUTION, Y-COORDINATES IDENTICAL*,4F10.4)
      RETURN
      END
```

```
      INTEGER FUNCTION QUAD(X,Y)
C--------THIS FUNCTION DETERMINES WHICH QUADRANT THE POINT (X,Y) IS IN.
C--------
C--------QUADRANTS ARE NUMBERED 0 - 3.
      IF (X) 25,40,30
C--------X IS LESS THAN ZERO, NOW CHECK Y
 25   IF (Y) 26,26,27
 26   QUAD = 2
      RETURN
C--------
 27   QUAD = 1
      RETURN
C--------X IS GREATER THAN ZERO, CHECK Y
 30   IF (Y) 31,33,33
 31   QUAD = 3
      RETURN
C--------
 33   QUAD = 0
      RETURN
C--------X IS ZERO, CHECK Y
 40   IF (Y) 41,50,43
 41   QUAD = 3
      RETURN
C--------
 43   QUAD = 1
      RETURN
C--------THE INTERIOR POINT IS A VERTEX
 50   QUAD = 4
      RETURN
      END
```


☆U.S. GOVERNMENT PRINTING OFFICE 1975 632-944/56 1-1